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DISCLAIMER

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ABSTRACT

This is a preliminary report dealing with the development of bakeable high-vacuum flanges for the ORNL PIG Facility. The general design approach for this type flange is to obtain a bakeable vacuum seal by first welding thin metal rings to a set of heavy metal flanges, and then edge-welding the rings together. This design allows the option of O-ring sealing for non-baked operation. A number of flange designs are discussed together with fabrication, inspection, testing, and installation and maintenance information.

INTRODUCTION

The following criteria were established for the design of bakeable high-vacuum flanges for the PIG facility:

1. Bakeable up to 500°C.
2. Sizes up to 18-inches outside diameter, mountable in any position.
3. Frequent opening and re-sealing not required.
4. Must be effective thermal barrier.
5. Adaptable to rubber O-rings for non-baked operation.
6. Vacuum tight during repeated thermal cycling.
7. Feasible with little or no development effort.

The basic plan was to design a flange which incorporated the ease and flexibility of O-ring seals for initial high vacuum operation, but which was capable of bakeout when ultra-high vacuum was desired. Speed and ease in making and breaking the bakeable seal was not considered essential, because the overall equipment design permitted access to the high-vacuum region through a low-vacuum region without breaking the high-vacuum seals. However, the ability to reuse a bakeable seal several times before replacement was considered desirable. Since not all parts of the PIG facility could be baked, it was necessary that several flange connections act as thermal barriers, thus eliminating a need for bellows. This flange had to be designed and constructed with a minimum of development effort, and with reasonable assurance of meeting the above basic criteria in sizes up to 18-inches outside diameter.

A flange design utilizing conventional bakeable seals such as gold O-rings or copper gaskets would satisfy most of the basic criteria, although some development effort might be required to perfect their use in larger flange sizes. However, it was felt that gold O-rings and copper gaskets could not withstand large thermal gradients without endangering the gasket sealing surfaces during differential expansion of the flange faces. For this reason it was felt a non-gasket type seal, such as obtained by welding a brazing, was necessary.

The presence of differential expansion movements between the flange faces dictated a seal design which could yield to the movement without excessively stressing the seal. Although several brazed joints were considered it soon became apparent that for this reason and several others (cleanliness, development effort, etc.), a welded closure design was preferable.

The first objective in arriving at a basic welded-closure design was to minimize the volume of fused metal to be removed during each opening. This was done by utilizing two thin metal sheets and edge welding. This seal-weld design approach offered low-fusion metal volumes, and could be incorporated into a welded-flange design by developing suitable techniques for welding thin metal sheets to heavy metal flanges. The small fusion metal volume increased the ease of opening and the number of possible openings before seal-ring replacement. The bellows-like arrangement of the thin seal rings permitted movement of the flange faces without excessively stressing the welds, and was a natural thermal barrier. The presence of flat flange surfaces made adaptability to O-ring sealing easy.

This seal-weld design approach was considered sufficiently promising to justify building a four-inch nominal prototype flange to test out welding and leak checking procedures, and leak rates during thermal cycling to 500°C. The encouraging results of these tests indicated extensive development work was not required. Therefore, this basic seal-weld design configuration was selected for scaling to all flange sizes, and the entire series of bakeable flanges, reducers, couplings, and tank closures discussed in this report were built for the PIG facility.

DESIGN

Outside Seal-Ring Flange

The basic flange design for the PIG facility is shown in Fig. 1. All flange parts are inconel, although other weldable materials might be used. The C-clamps are required on larger flanges if the axial loading is sufficient to separate the flange faces when not under vacuum. Small flanges of this design usually do not require clamping. The lugs machined into the male flange act as radial support members and axially align the flanges. They also provide a set spacing between the flange faces. In the first designs this spacing was adjusted to give about 0.040-inches gap between the seal rings. Later, experience indicated this gap should be reduced to about 0.010-inches to minimize strain on the base weld and still provide adequate pump-out space.

Seal rings of 0.015 to 0.025-inches thickness have been used. The thinner rings have the advantage of greater flexibility when a large thermal gradient is applied, but the thicker rings are favored because of greater ease and reliability of welding, and increased protection against damage during handling. Early designs using 0.015-inch rings were easily damaged before the seal weld was made. The desirability of using even thicker seal rings is now being investigated. Of course, the ultimate limitations are loss of flexibility, and increased fusion metal volume to be removed during each opening. The radial width of the seal ring is controlled by the available C-clamp sizes and the number of closures desired before seal-ring

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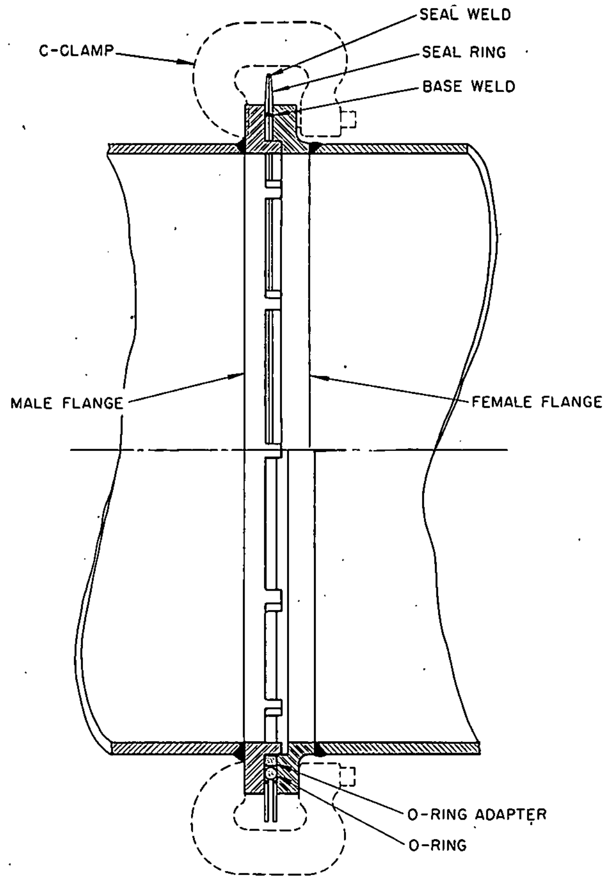

Fig. 1. Outside Seal-Ring Flange.

replacement. If C-clamps are not required, wider seal rings are favored because of their greater flexibility and number of possible closures before replacement.

The outside seal-ring flange is adaptable to O-ring sealing, as shown in the bottom section of Fig. 1. The correct inside diameter and squeeze for the O-ring is provided by the O-ring adapter. This brass adapter ring is held in place by the male lugs. The C-clamps are now essential to start the sealing action. All flange dimensions are balanced to fit commercially available C-clamps and O-rings.

Note, the male lug and seal-ring configuration yields a very small cross-sectional area for thermal conduction. Excellent thermal isolation is thus available when the flange must join baked and unbaked portions of a vacuum system. If thermal isolation is of principal importance the number of male lugs may be reduced and other techniques, such as nickel plating the flange faces, applied to reduce heat transfer. For instance, on a 12-inch nominal flange the total cross-sectional area for thermal conduction can be reduced to less than one square inch.

In order to utilize this type flange design it was necessary to develop techniques for welding the thin inconel seal rings to the heavy inconel flanges. The jig developed for making the base weld is shown in Fig. 2. This jig holds the seal ring securely in place while the base weld is being made. It consists of a hold-down ring which holds the seal-ring flat against the flange face, and an alignment ring which positions the seal ring with respect to the flange axis. This ring is split to permit removal over the flange face. The clamping lugs supply the force required to hold the jig firmly in place. The cap screw is counterbored to give a smooth surface for guiding the welder's hand. The jig is all copper to insure

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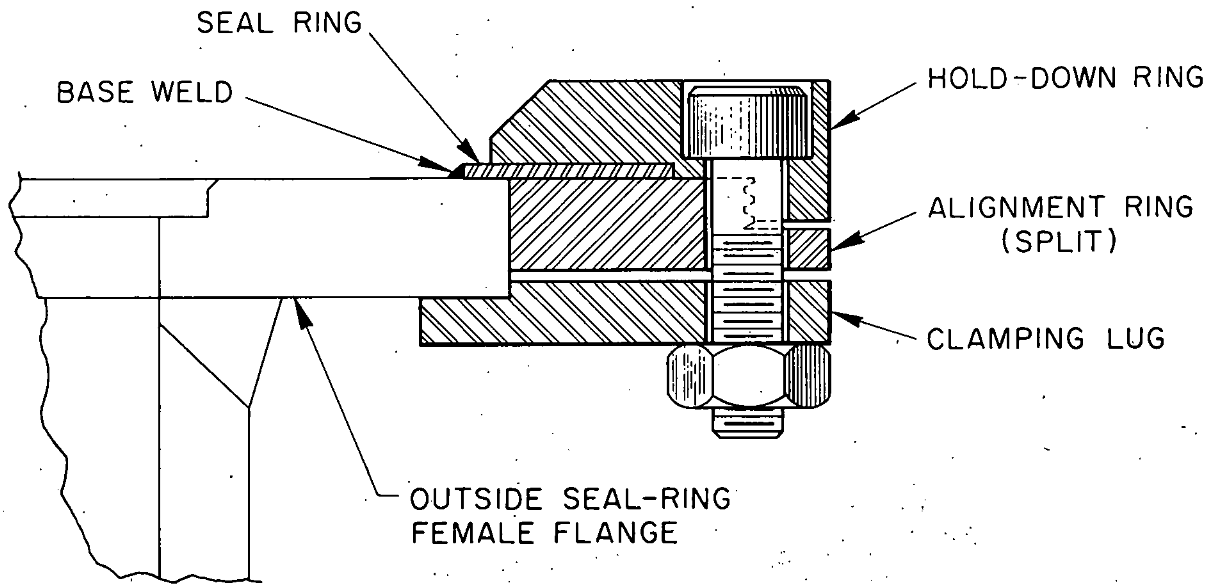

Fig. 2. Outside Base-Welding Jig.

quick heat removal from the weld area and to freeze the weld bead if it burns close to the flange edge. The base weld is about 1/8 inches from the flange edge and the hold-down ring about 1/16 inches. A separate base-welding jig of this same general design is required for each flange size. A photograph of a 12-inch outside base-welding jig in use on the PIG facility is shown in Fig. 3. This photograph was taken after completion of the base weld.

The seal weld on this type flange is made by clamping a portion of the total seal ring circumference with the jig shown in Fig. 4. This jig pulls the seal rings tightly together and irons out surface irregularities. The jig is all copper to provide quick weld cooling and to freeze the weld in the event it burns too deeply. The V-shape configuration helps to retain the inert gas atmosphere around the weld area. No back-up gas behind the weld is required. The radius of the welding jig is usually specified as the outside radius of the flange to be welded. This allows the jig to fit-up when the seal weld is closed for the last time before seal-ring replacement. The width of the jig faces at the base is determined by the minimum amount of seal ring to be left after the last seal weld is made. With the jig radius matched to the flange radius, the jig will not fit up along its full circumference the first few times the seal weld is made. A weld jig of larger radius could be made for this situation, but it is sufficiently fast to make one or two additional setups for the larger radius welds. This is not difficult, since the jig slides easily around the circumference of the seal ring. The circumferential length of the jig is usually held to about six to eight inches in order to maintain adequate compressive force at the center when bolted at each end. The clearance between the V-point of the welding jig and the seal weld should be 1/32 to 1/16 inches.

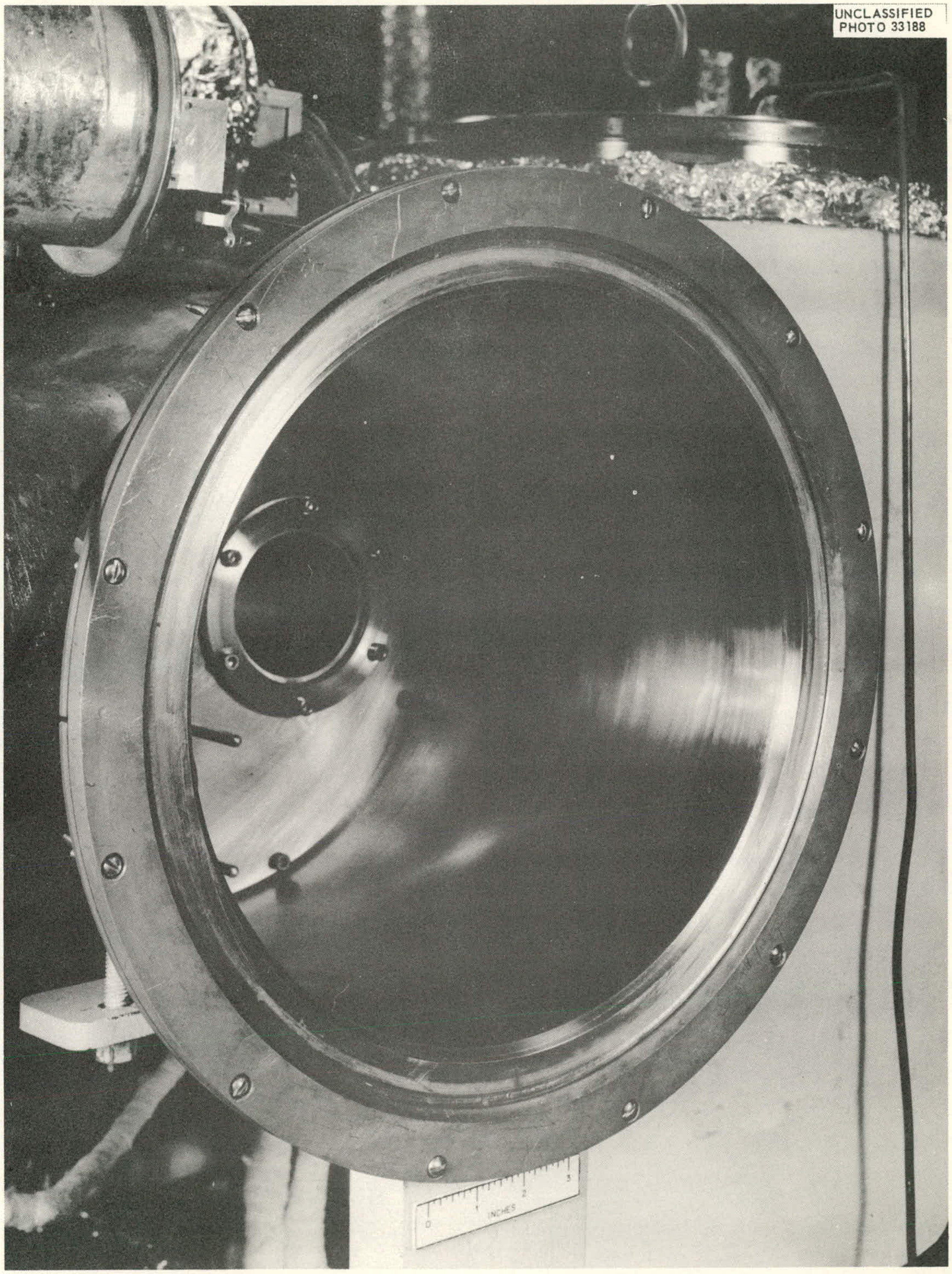

Fig. 3. Outside Base Welding on PIG Facility.

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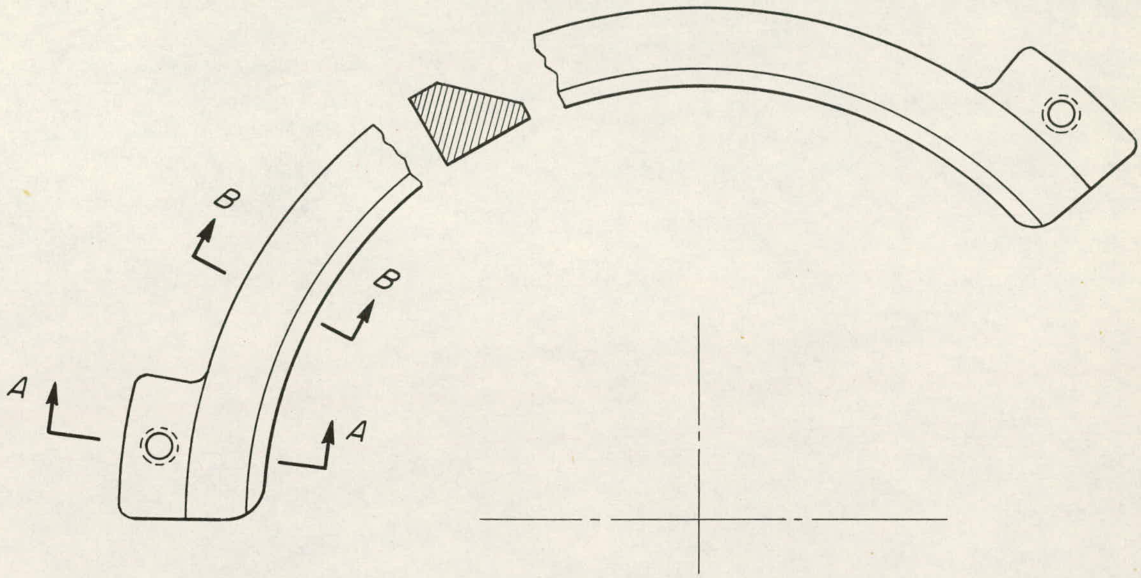

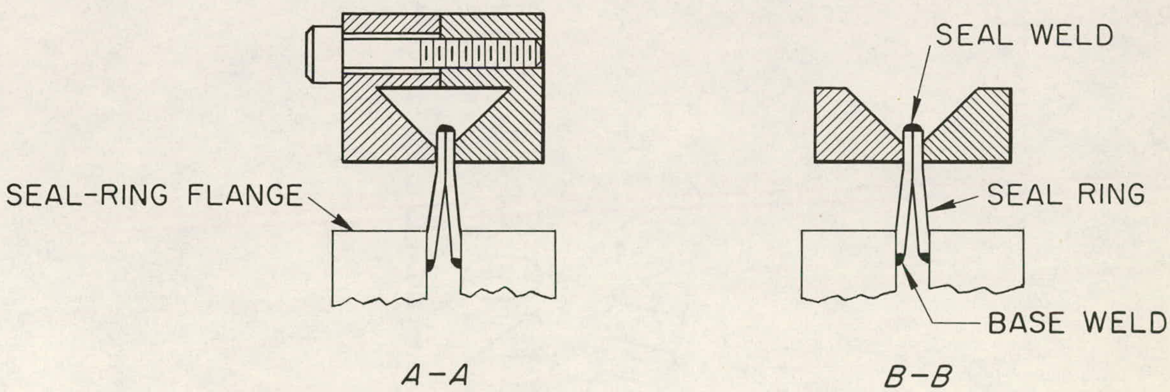

Fig. 4. Outside Seal-Welding Jig.

Figure 5 shows a jig in use on an 11-inch nominal outside seal-ring flange. This photograph was taken after completion of the seal weld.

An interesting modification of the outside seal-ring flange is to design it with an inside bolted closure. This design offers the distinct advantage of taking up very little outside space for closure. This is particularly important when magnetic field coils must be fitted tightly over a vacuum tank, and vacuum pumping manifolds attached behind the coils. The only design limitation is the requirement that the inside bolt circle be accessible from some other place in the system. The outside seal-ring flange can also be designed with an outside bolted closure. A split ring with a bolt circle outside the seal ring is required. This ring applies clamping pressure from the back faces of the flange set.

Inside Seal-Ring Flange

The basic design of the outside seal-ring flange with inside bolted closure can be inverted to give the inside seal-ring flange shown in Fig. 6. The inside seal-ring flange can be used only for larger diameter pipe, and under conditions where the seal ring is accessible for seal welding. For joining pipes or tanks of equal diameter it is inferior to the outside seal-ring flange with inside bolted closure, unless it is essential that the inside bore remain unobstructed. This was the problem of joint design on the PIG facility at the point where the vacuum tank center section joined the 10-inch pumping manifolds. This bakeable closure had to retain the same inside diameter as the center section, and a flange width of less than one inch in order to accommodate magnetic field coils close to the outside diameter. No space was available for C-clamping so a bolted closure design was essential. For this case the inside seal-ring flange

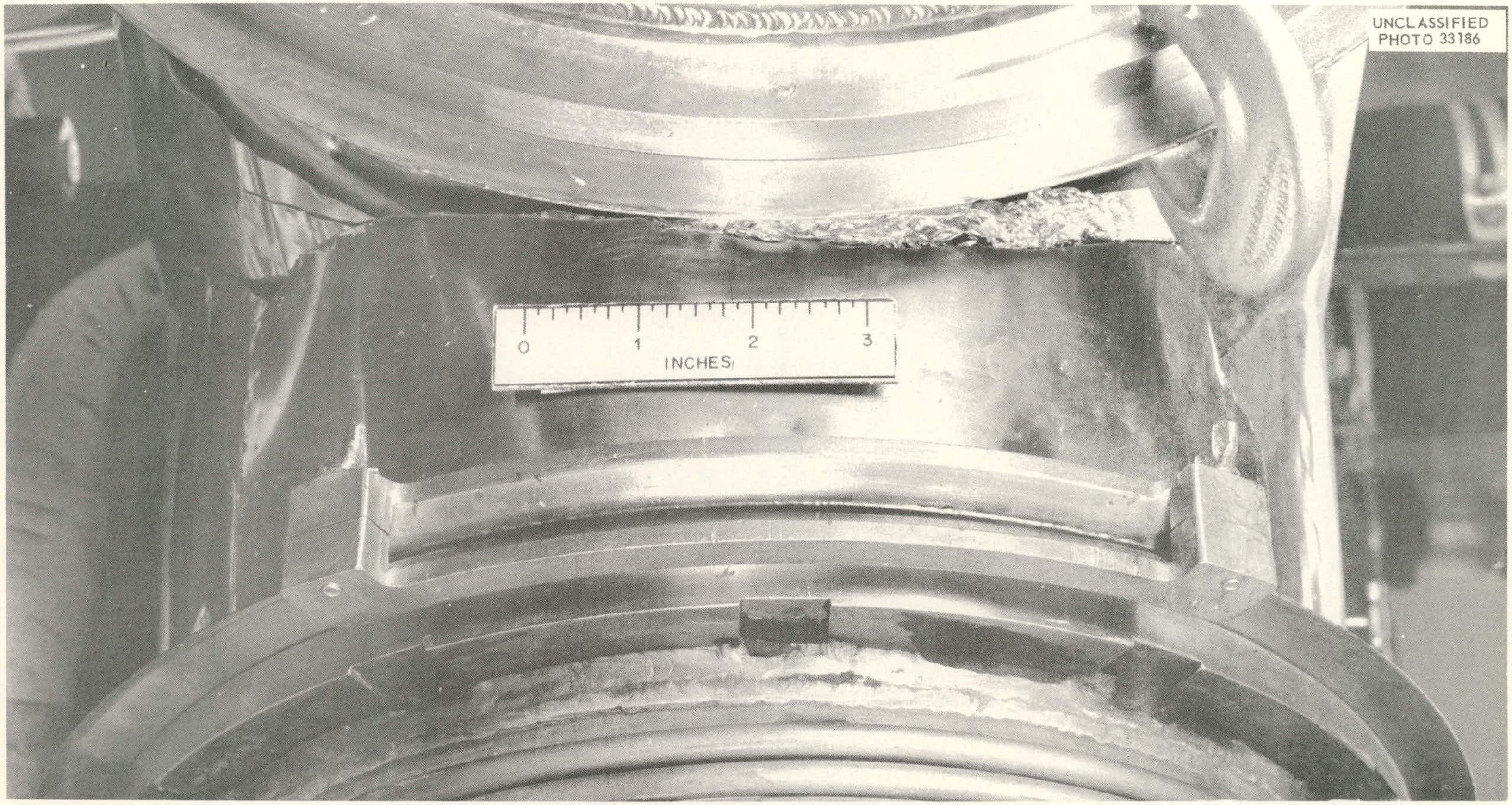

Fig. 5. Outside Seal Welding on PIG Facility.

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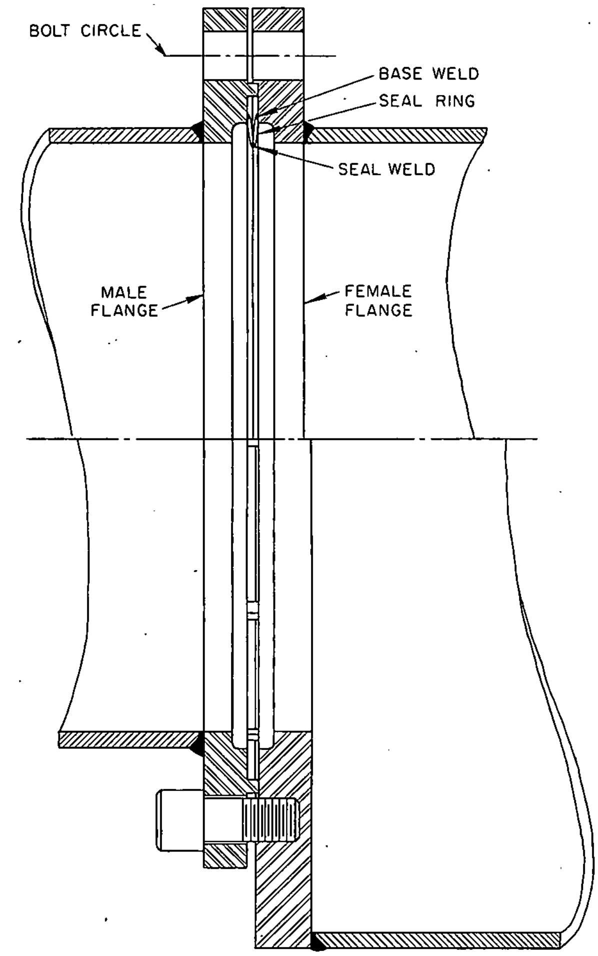

Fig. 6. Inside Seal-Ring Flange.

was carefully scaled down by shortening the bolt circle and providing less clearance between the base weld and bolt holes. A flange width of one inch was achieved.

One of the advantages of the inside seal-ring flange becomes evident when it is necessary to join a pipe to a large vacuum manifold or to join two vastly different diameter pipes, as shown in the bottom section of Fig. 6 (seal ring omitted for clarity). It can be applied to real advantage as a reducing closure if the weld area is sufficiently accessible. One of the merits of this type design is its full accessibility for cleaning on the high vacuum side. The outside seal-ring flanges are definitely inferior in this respect.

The base-welding jig for this type flange is shown in Fig. 7. As in the case of the outside base-welding jig, a hold-down ring is used to hold the seal ring flat against the flange face while an alignment ring centers it with respect to the flange axis. In this case the alignment ring is cut into quadrants to facilitate removal after the base weld is completed. Clamping plate pressure is obtained by passing a long bolt through the plate and along the flange axis to a second clamping plate at the opposite end of the tank or pipe. The entire jig is made of copper to keep the weld area cool and freeze the weld if it burns too deeply.

The inside seal-welding jig is shown in Fig. 8. This jig is identical in principal to the outside seal-welding jig. Its cross section must be smaller to accommodate the shorter seal rings. This jig will not yield a large clamping pressure at the center when the end bolts are tightened, but any desired pressure can be obtained by driving small shims between the jig and the flange. By using a small copper cross section on the jig, and

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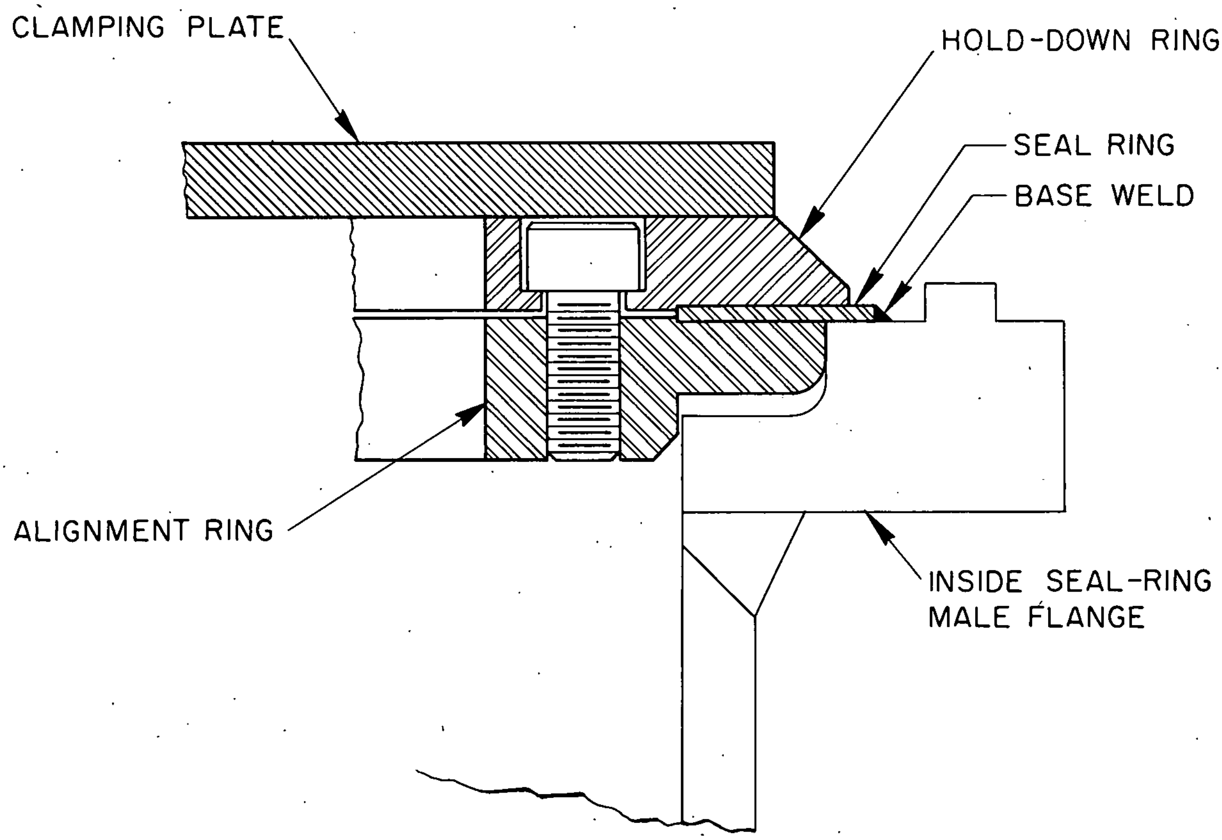

Fig. 7. Inside Base-Welding Jig.

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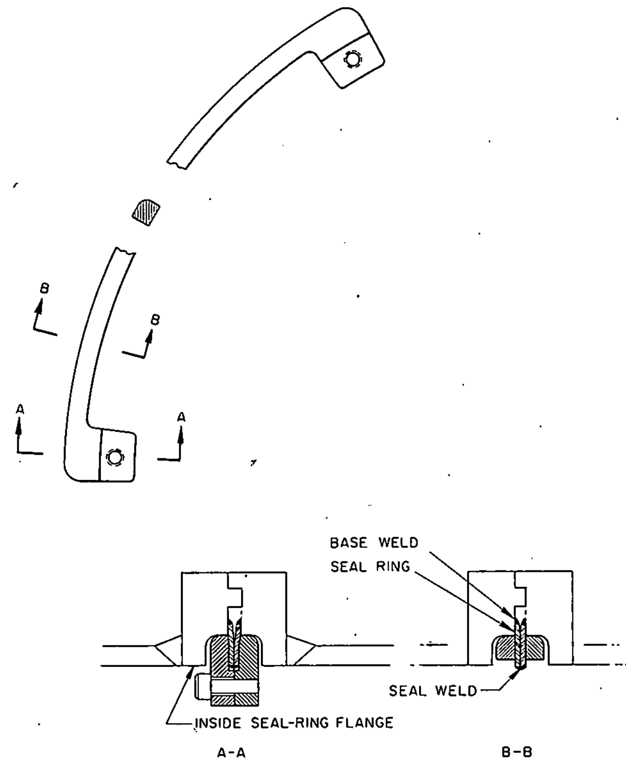

Fig. 8. Inside Seal-Welding Jig.

designing the jig to match the inside diameter of the flange groove, it is possible to obtain two seal welds from a given set of seal rings.

The inside seal-ring flange can be designed for O-ring sealing by using an O-ring adapter similar to the one used with the outside seal-ring flange. This adapter fits over the lugs of the male flange. A larger bolt circle is required.

Seal-Ring Tubing Coupling

The basic seal-ring flange design can be applied to join thin wall tubing with a bakeable joint, as shown in Fig. 9. This tubing coupling is a modified outside seal-ring flange. Type A coupling is designed to give a small axial spacing between the flange faces. Ordinarily, the type B coupling is preferred because of its greater simplicity. The type B coupling is shown with a slip-on type flange design. Other welded joint designs can be used.

This seal-ring tubing coupling is designed for small diameter thin-wall tubing. Unless large axial tensil forces are applied, it is not necessary to use flange clamping. The jigs and fixtures required to weld this coupling are identical in principal to those used for the outside seal-ring flange.

Seal-Ring Pipe Coupling and Tank Closure

The seal-ring closure principal can be used to provide a simple method for joining two pipes together in a bakeable fashion, as shown in Fig. 10. For standard wall pipe, the wall thickness is sufficient to permit the seal ring to be welded directly to the pipe wall. The only machine operation required is to take a cut on the pipe wall face to provide a flat surface

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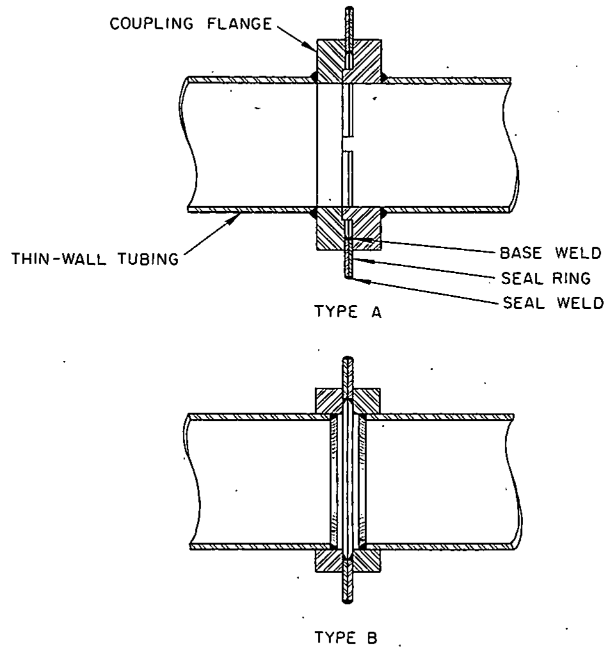

Fig. 9. Seal-Ring Tubing Coupling.

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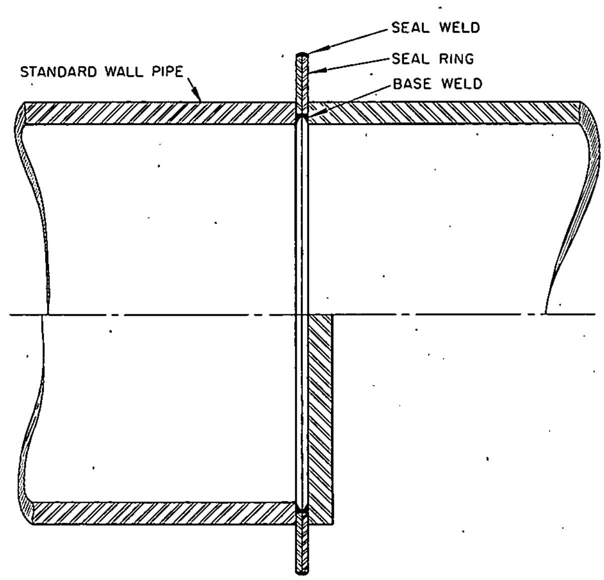

Fig. 10. Seal-Ring Pipe Coupling and Tank Closure.

for welding the seal ring. The jigs used for this coupling are essentially those required for an outside seal-ring flange. In place of the clamping lugs it is necessary to provide a modified clamping arrangement. For short pipes the clamping bolts can be extended to the opposite face of the pipe. For long pipes ears may be welded to the pipe with holes for clamping bolts. For most coupling situations the seal rings have been found sufficiently rigid. If additional stability should be desired, pins can be welded to the inside diameter of one pipe to guide it into the mating pipe when the coupling is made up.

Closely akin to the seal-ring pipe coupling is the seal-ring tank closure shown in the bottom section of Fig. 10. This closure is designed for large vacuum tanks such as liquid nitrogen cold traps. It is simple and can be made bakeable and vacuum tight in very large sizes. If desired, pins may be attached to the cover plate to provide additional stability.

Other Configurations

The welded seal-ring closure principle is not limited to circular configurations. In fact, the flange shape is limited only by the ability to fabricate the flange, welding jigs, and seal rings.

Thermal Gradient Problems

When using seal-ring flanges in an application where large thermal gradients are likely to appear, it is essential that the female flange be placed on the higher temperature side. This eliminates the possibility of breaking the male lugs, which might occur if they expanded against the female groove. A flange experiencing large thermal gradients should also be provided with larger seal-rings to help absorb the differential movement.

Materials

Thus far, most of the seal-ring flanges have been fabricated from inconel. Some carbon-steel vacuum tank closures using carbon-steel seal rings have been made, and on one occasion a carbon-steel tank closure was successfully made using inconel seal rings. Other material combinations are now being tested.

FABRICATION

Tolerances

If the seal rings are to line up along the seal-welding edge after flange assembly, it is essential that each seal ring be positioned concentric with the flange axis before welding, and that the flanges be on a common axis. To do this requires decimal tolerance machining of several parts of the male and female flanges, and the seal rings and welding jig. Although some of the first flange designs were built to decimal tolerances, and did provide excellent lineup, later experience has indicated the additional fabrication expense is not justifiable. The desirable alternative is to apply the usual fractional shop tolerances to all dimensions and allow the seal rings to align as will. After the base welding is completed and the flanges assembled, the seal-ring edge can be hand-dressed with a file or grinder for true fit-up before the first seal welding. If the flanges are indexed, this operation need not be repeated until new seal rings are attached. This procedure has proved very satisfactory, and is now recommended. Adopting this approach greatly reduces the cost of making a flange set and tooling-up for welding. The only close machining required is on the squeeze dimension of the O-ring adapter. No fine surface finishes are necessary.

Welding

Controlled atmosphere, direct-current, electric arc welding is used exclusively for the base and seal welds. The controlled atmosphere is high-purity argon. The welding current is about 20 to 30 amperes. It is essential to vacuum-tight welding that all parts of the flange and welding jigs in the weld area be thoroughly cleaned before welding. The most satisfactory cleaning fluid used thus far has been acetone.

Seal-Ring Cutting

The seal rings are cut on a lathe, using a set of dies similar to those shown in Fig. 11. The cold-rolled sheet stock is first annealed to improve its machinability and give greater flexibility to the finished ring. It is then placed in the large set of disc dies shown on the right and jigged tight between the chuck and tail stock of a lathe. After the outside diameter is cut, the metal discs are placed in the die, shown on the left, and chucked in a lathe to cut the inside diameter. About 10 to 15 seal rings can be cut at one time by this technique.

INSPECTION AND TESTING

Weld Inspection

All base and seam welds are visually inspected with the aid of liquid dye penetrant and developer (such as Spotcheck, Magnaflux Corporation, Chicago). Experience has shown that all imperfections, which retain any dye penetrant after cleaning and developing, must be ground out and rewelded. A small electric hand grinder, such as used by model makers, is a suitable tool for grinding. Thus far, experience has shown that all vacuum leaks

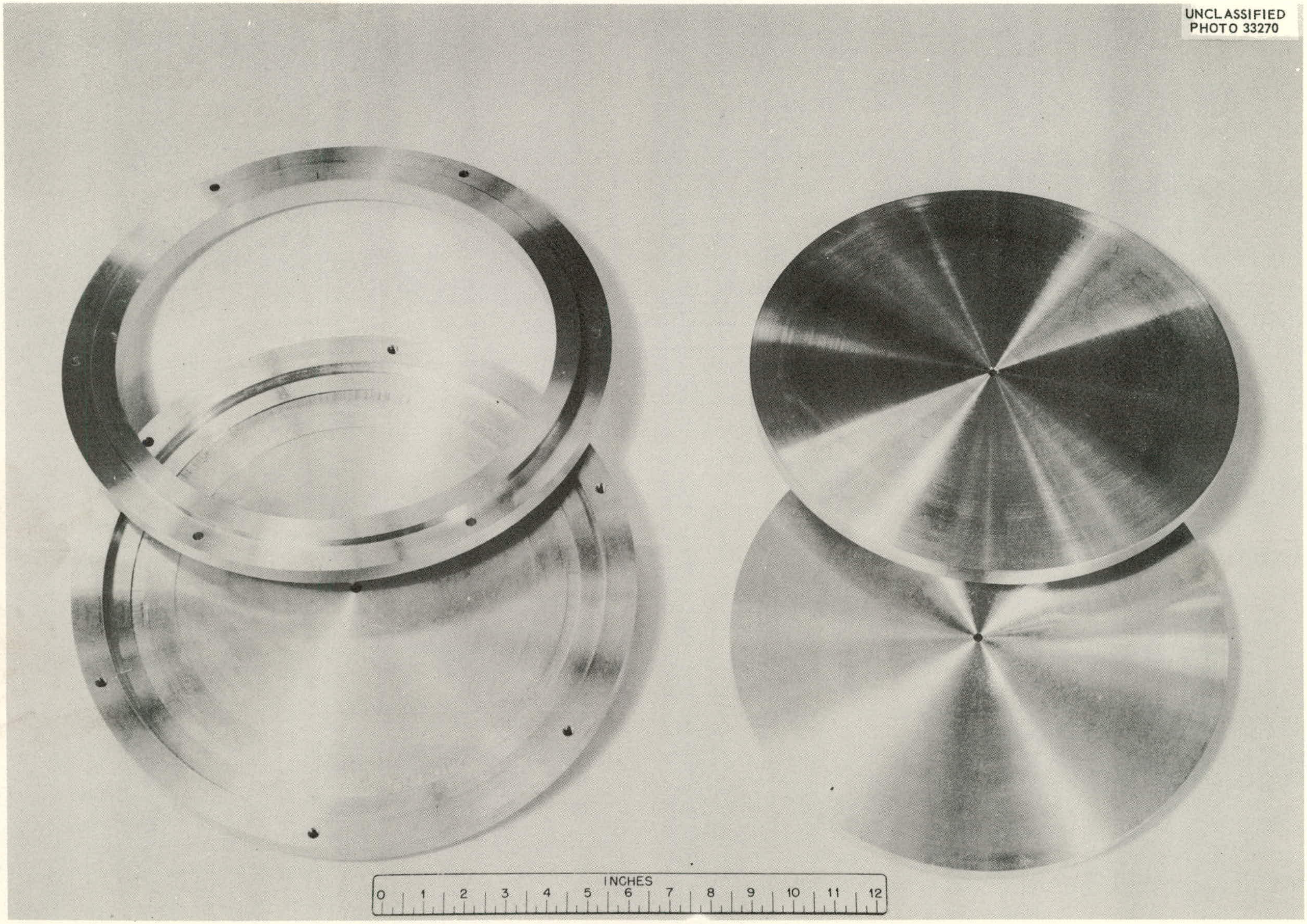

Fig. 11. Dies for Cutting Seal Rings.

can be predicted with a careful dye penetrant test. Of course, the weld inspector must be trained to interpret the test in terms of vacuum service.

Leak Checking

After a base weld has been dye checked and repaired, it is helium-leak checked. The leak check on the base weld is accomplished with the aid of a leak-checking ring. This ring is made from 1/4 x 1/4-inch hollow copper and designed to fit behind the seal ring, as shown in Fig. 12. Holes drilled along the inside edge of the ring fit up to the base weld region behind the seal ring. Duxseal (Johns Manville Product) is then applied to the outside area of the checking ring to obtain a vacuum tight seal. Using this technique, it is possible to pull vacuum on the base weld and use the helium-leak test.

Following through this careful inspection program on each weld insures leak tightness when the flanges are assembled and the seal weld made. The seal weld is checked after the flange assembly is under vacuum. If a seal weld leak occurs, it can be repaired in place. Base welds on inside seal-ring flanges may be helium-leak checked by using a similar technique.

Thermal Gradient and Cycle Tests

Time was not originally available for extensive laboratory development and testing of the seal-ring type flange. Some quick experiments were conducted to test out welding and leak checking procedures, and leak rates during the application of thermal cycles and thermal gradients. A 4-inch nominal (5-1/2-inch outside diameter) outside seal-ring flange was fabricated for this purpose. Figure 13 shows the experimental setup used for the thermal tests. The test flange was placed on a 2-kw. hot plate.

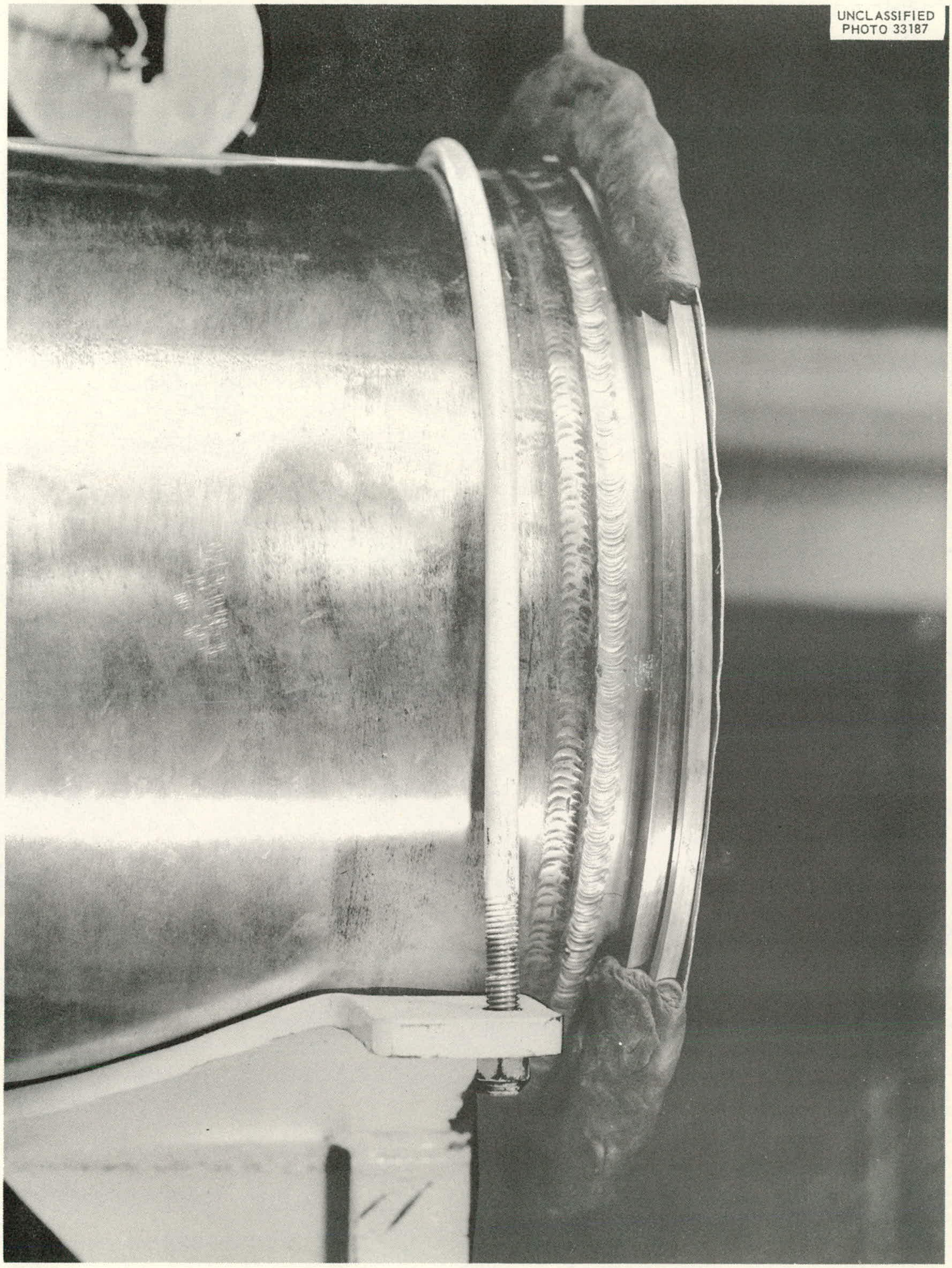

Fig. 12. Outside Base Weld Leak Checking on PIG Facility.

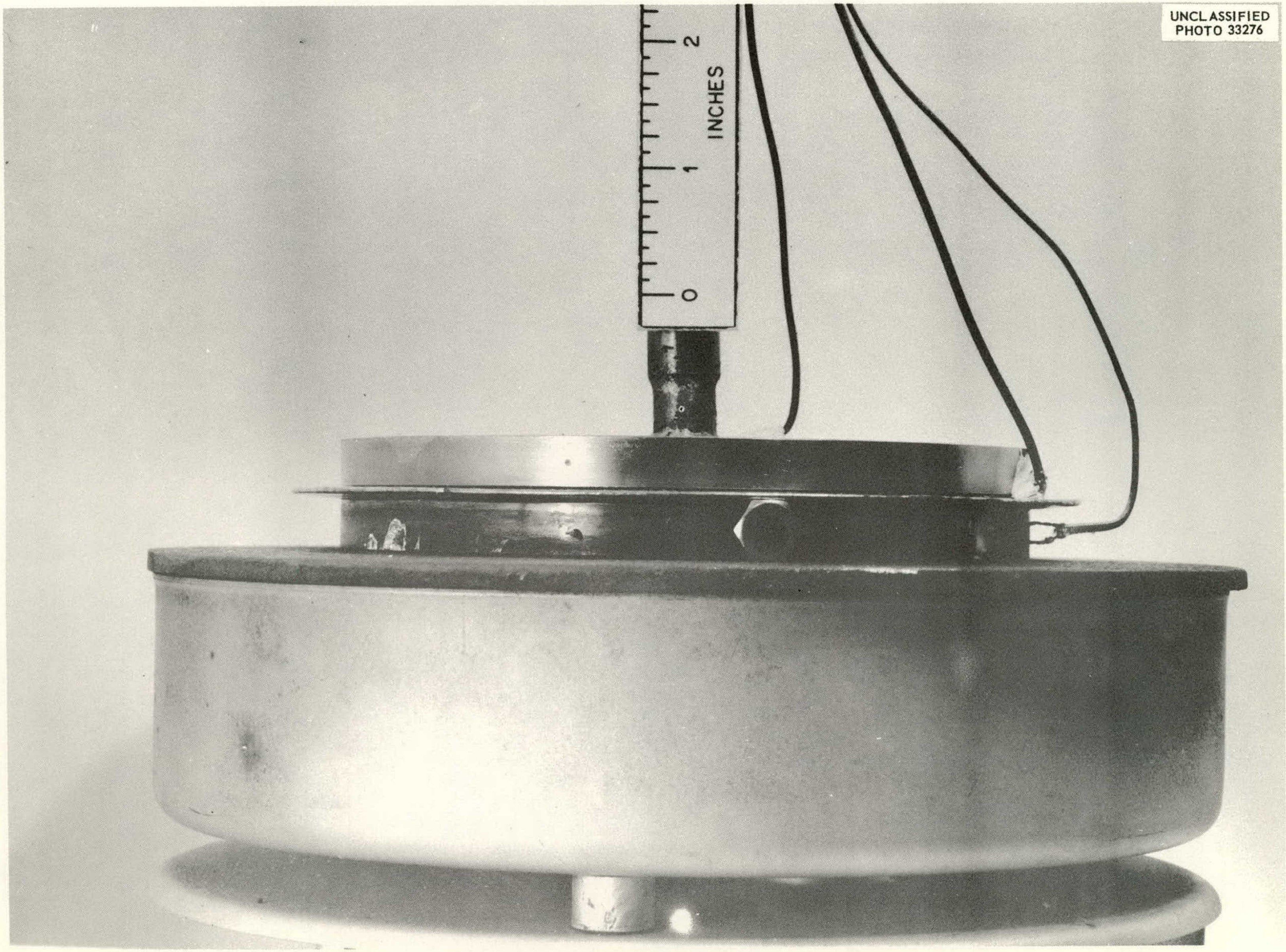

Fig. 13. Prototype Outside Seal-Ring Flange Before Heating.

Thermocouples were located at the following points:

Point No. 1. Inside center of bottom flange.

2. Outside periphery of bottom flange.

3. Center of top seal ring.

4. Outside center of top flange.

5. Inside center of top flange.

The hot plate heated the bottom flange to about 600°C. Natural convection cooling brought the top flange into equilibrium at about 270°C. In order to obtain a more severe thermal gradient, the hot plate was insulated with aluminum paper and the top flange cooled with air and breakers of boiling water. For this condition, the bottom flange came up to 700°C and the top flange down to 185°C.

Figure 13 shows the test flange before heating. Note the hexagonal bolt head on the hot plate just clears the seal weld. Figure 14 shows the same flange after heating to 580°C on the bottom flange. Note the seal ring curl due to expansion of the bottom flange. The hexagonal bolt head now clears the seal weld by 1/16 inches. A maximum thermal gradient condition was established by adding insulation and cooling. The recorded temperatures for both cases are given below:

Point No.	As Photographed	Maximum Reached
1	580°C	700°C
2	585	625
3	350	285
4	275	182
5	260	185
Max. Gradient	325°C	515°C

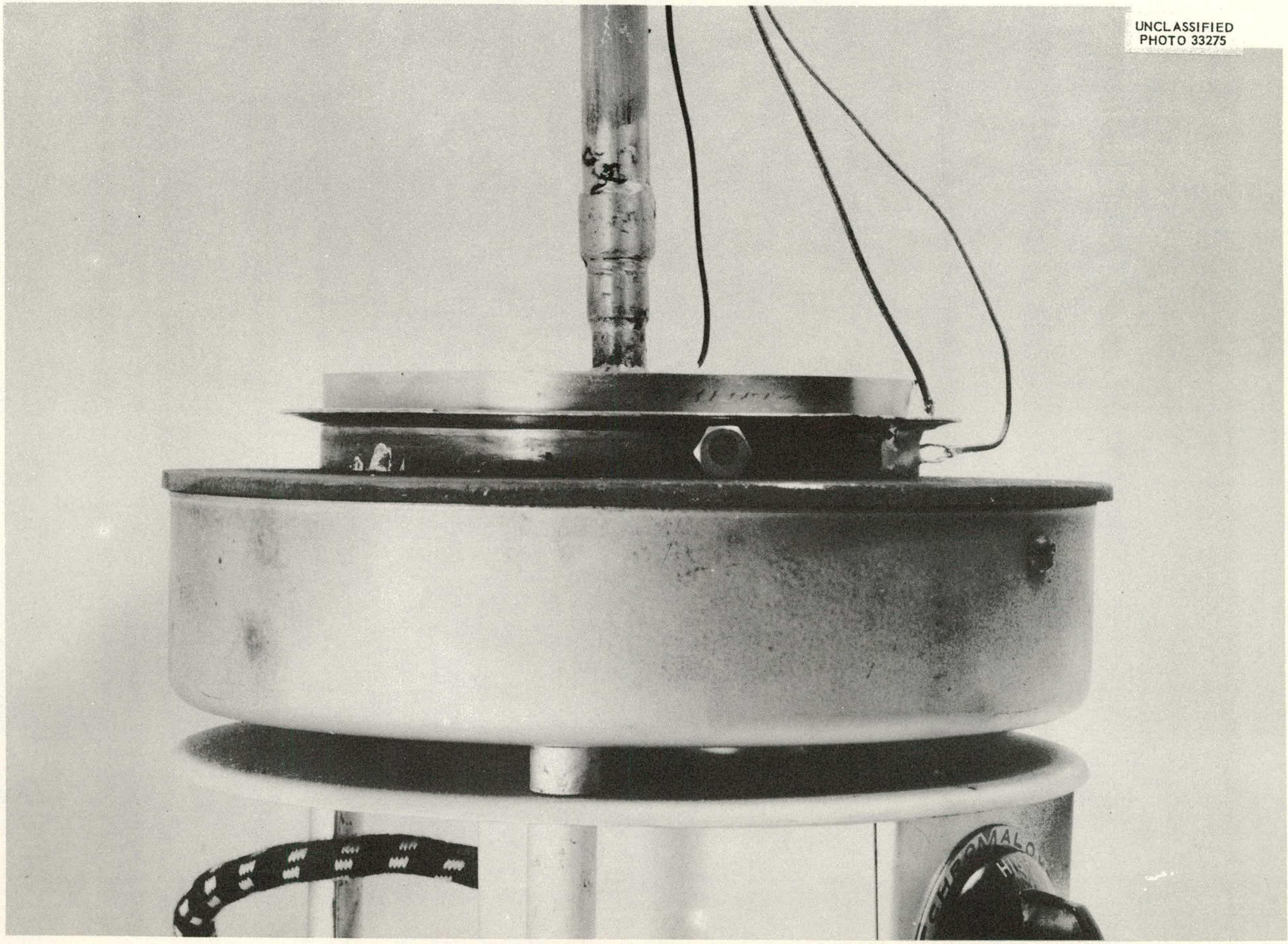

Fig. 14. Prototype Outside Seal-Ring Flange with 325°C Thermal Gradient.

The effect of repeated thermal cycling was tested by heating the bottom flange to 600°C (about 270°C lower on top flange) and then rapidly cooling by placing the hot flange assembly on a cold aluminum plate. This cycle was repeated ten times before a silver soldered joint on the pump-out stem failed. A new set of seal rings were attached to the flange and the cycling repeated ten times without detectable leakage (leak detector maximum sensitivity 1 part in 10^7). Because of the encouraging results of this test, no additional prototype testing or development work was considered necessary before going to full scale designs.

INSTALLATION AND MAINTENANCE

Space Requirements

The principal problem of installing the seal-ring type flange is that of space. Ordinary bolted closures can be placed in rather cramped quarters, but the seal-ring flange must have sufficient access to its periphery to make seal welding and seal weld removal possible. This is not a severe limitation on a large machine such as the PIG Facility, but it could be a troublesome limitation if a small compact vacuum system were contemplated.

A general criteria for welding clearance is to have the weld area sufficiently clear of equipment from the welding direction to allow the welder's hood to approach to within at least 18 inches of the weld area. Special small welding hoods can be used where space is limited. A torch space two inches wide and three inches high is considered minimum for seal welding. In general, the welder must have sufficient space to manipulate his torch and see his weld.

Experience has indicated inside seal welding on pipes four-inches nominal and up is not practical if the weld area is in a distance greater than one and one-quarter pipe diameters. Seal weld removal can be accomplished in the same space as required for welding.

Seal Weld and Base Weld Removal

Thus far, the simplest technique found for removing seal welds has been to hand-cut them using a sharp file. Only three or four strokes of the file are usually required to cut through the weld. The file strokes should be along the seal weld---not across it. One advantage of the file over other devices, such as a hand grinder, is the smaller working space required and the greater control over cutting depth. Longer seal ring life results if only the fusion metal is removed. The time required to remove a seal weld is about 15 to 20 minutes for a 12-inch outside seal ring flange. An inside seal weld must be removed with a hand grinder.

After the useful part of the seal ring has been consumed, it is removed by cutting it off with a hammer and chisel from the back side of the base weld. The small weld bead which remains after removal of the seal ring must be hand-dressed with a grinder to provide a level surface for a new seal ring. This removal and dressing operation takes about one hour for a 12-inch outside seal-ring flange. If the flange is designed for an O-ring adapter it is necessary to exercise care to avoid scratching the O-ring seating surface during base weld removal.

Leak Sealing

If a vacuum leak should open up in a seal or base weld during operation it can be successfully closed with Dow Silicone 997 impregnating varnish. This varnish has been used with a good degree of success and it remains plastic even at 425°C. One precaution is to use it sparingly. If applied extensively it has been known to form long capillary paths from the actual leak to the outside environment. These long leakage paths introduce time delays which make leak detecting difficult and untrustworthy. Xeylene can be used as a solvent to thin the varnish for better penetration into fine cracks, or as a cleaning agent to remove excess varnish. Note, the outside seal-ring flanges are well adapted to sealing with varnish because both the base and seal welds are readily accessible. When inside seal-ring flanges are used, it is important to provide a gap of at least 1/32 inches between the flange faces in order to allow sealing varnish to be injected into a leak with a hypodermic syringe.

SUMMARY

Advantages

In summary, the advantages of the seal-ring type flange design may be listed as follows:

1. Low cost per closure when used in large numbers of a given size.
2. Low cost per closure for odd closure configurations.
3. No tight tolerances or fine surface finishes required.
4. Will withstand large thermal gradients (good thermal barrier) and repeated thermal cycling without measurable leakage.
5. Bakeout temperature limited only by strength of vacuum container.
6. Mountable in any position.
7. Size limited only by ability to fabricate suitable welding jigs and fixtures.
8. Most designs easily adaptable to O-ring closure for non-baked operation.

Disadvantages

The disadvantages of the design are:

1. Cannot be quickly opened and resealed.
2. High cost per closure when used in small numbers of a given size.
3. Must have adequate welding space.
4. Requires welding equipment and skilled welder.
5. Requires lengthy inspection and leak checking before use.
6. Seal rings easily damaged before seal welding.
7. Outside seal rings cannot be cleaned inside without disassembly.

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