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TOROID ROTATOR FOR SMALL-SCALE DYNAMIC CORROSION STUDIES - DESIGN, FABRICATION, AND OPERATION

R. M. Warner
G. E. Moore
H. C. Savage

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ORNL-2870
Equipment, Methods, and Techniques

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REACTOR EXPERIMENTAL ENGINEERING DIVISION

TOROID ROTATOR FOR SMALL-SCALE DYNAMIC CORROSION STUDIES – DESIGN, FABRICATION, AND OPERATION

R. M. Warner, G. E. Moore, and H. C. Savage

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FOREWORD

Corrosion studies in the Homogeneous Reactor Project are conducted by the Corrosion Section of the Reactor Experimental Engineering Division, and these studies are under the general supervision of E. G. Bohlmann, Assistant Director of the Division. The work described in this report was performed by E. L. Compere, R. A. Lorenz, G. E. Moore, H. C. Savage, and R. M. Warner.

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TOROID ROTATOR FOR SMALL-SCALE DYNAMIC CORROSION STUDIES--DESIGN, FABRICATION, AND OPERATION

ABSTRACT

A description of the four-toroid rotator, a relatively simple apparatus particularly applicable to the determination of the corrosive effects of flowing solutions or slurries on structural materials, is presented in detail. In this apparatus flow of a liquid medium at known velocities is induced in a circular section of pipe without the use of pumps. Included in this report are details of mechanical design, descriptions of equipment and instrumentation, a list of fabrication costs, and a discussion of operational experience.

1. INTRODUCTION

The corrosion of metals by solutions and thorium oxide or thorium-uranium oxide slurries of reactor fuel materials is being studied extensively at ORNL. In this program materials are tested under both static and dynamic conditions.

Although static tests are useful in determining the chemical resistance to corrosion, dynamic tests are required to duplicate the flow conditions existing in an aqueous homogeneous reactor to gauge the effect of flow velocity and turbulence on the corrosion process. In the case of thorium oxide slurries, agitation and/or circulation of the slurry is necessary to maintain a homogeneous suspension of the thoria in an aqueous media. Further, erosion of the containment materials by the thoria particles is an important corrosion variable in a slurry system. Degradation of the slurry particles with resultant changes in the handling characteristics may also occur under dynamic conditions. One type of apparatus which has been useful in the dynamic corrosion test program is a toroid rotator.

The toroid rotator described in this report is an economical laboratory-scale apparatus that provides a method of circulating fluids at known velocities up to approximately 45 fps without the use of a pump. The toroid itself is compact and requires only a small amount (20 to 25 ml) of test solution and materials. This is advantageous where cost or amount of material available is of importance. A heating system is provided for operation at temperatures up to 300°C, and pressures up to 2000 psia can be contained. The system pressure can be continuously measured and recorded if desired.

2. MECHANICAL DESIGN

2.1 Original Conception and Development

The original conception of the toroid apparatus should be credited to L. G. Desmond and D. R. Mosher of the National Advisory Committee for Aeronautics.[1] In mid-1951 they experimented with the circulation of a fluid through a loop of pipe, or toroid, by developing a method of imparting the requisite motion to the loop, an action similar to swirling water in a flask. Using this principle a similar device was developed and perfected here at ORNL.

2.2 Circulating Apparatus

To attain the circular motion required to impart flow in the toroid, a horizontal mounting plate is attached at its center (by means of a bearing) to the shaft of a vertical rotator arm (see Fig. 1). The rotator arm is in turn connected to the shaft of a variable-speed motor mounted vertically. The vertical center line of the shaft of the rotator arm, which is connected to the mounting plate, is offset from the center line of the motor shaft, thus creating a crank throw in the rotator arm. The horizontal plate, with attached toroid, is prevented from rotating about its own axis by a connecting rod installed between the plate and a rigid frame. Hence rotation of the motor shaft results in motion of the assembly such that any point on its surface describes a circle with radius equal to the crank throw in the rotator arm.

The circulating loop, a length of 3/8-in. sched-40 pipe with its ends joined to form a circle 5 19/32 in. in diameter, is mounted on the horizontal plate. It is apparent from consideration of the geometry of the apparatus that, as the rotator arm turns, the point on the toroid which is farthest from the center of rotation is on a straight line passing through the centers of the rotator-arm shaft and the motor shaft. When the toroid is partially filled with fluid, a slug of fluid is formed, the center of gravity of which tends to approach the point of greatest radius as a result of centrifugal force. This point of greatest radius moves around the toroid, making one revolution for every revolution of the rotator arm and/or motor shaft. Hence, the fluid within the toroid makes one complete circuit of the toroid for every revolution of the motor shaft. The velocity of the fluid flowing around the toroid is given by

$$V = 2\pi RN$$

[1] L. G. Desmond and D. R. Mosher, "Preliminary Study of Circulation in an Apparatus Suitable for Determining Corrosive Effects of Hot Flowing Liquids," NACA Research Memorandum No. E51D12 (June 29, 1951).

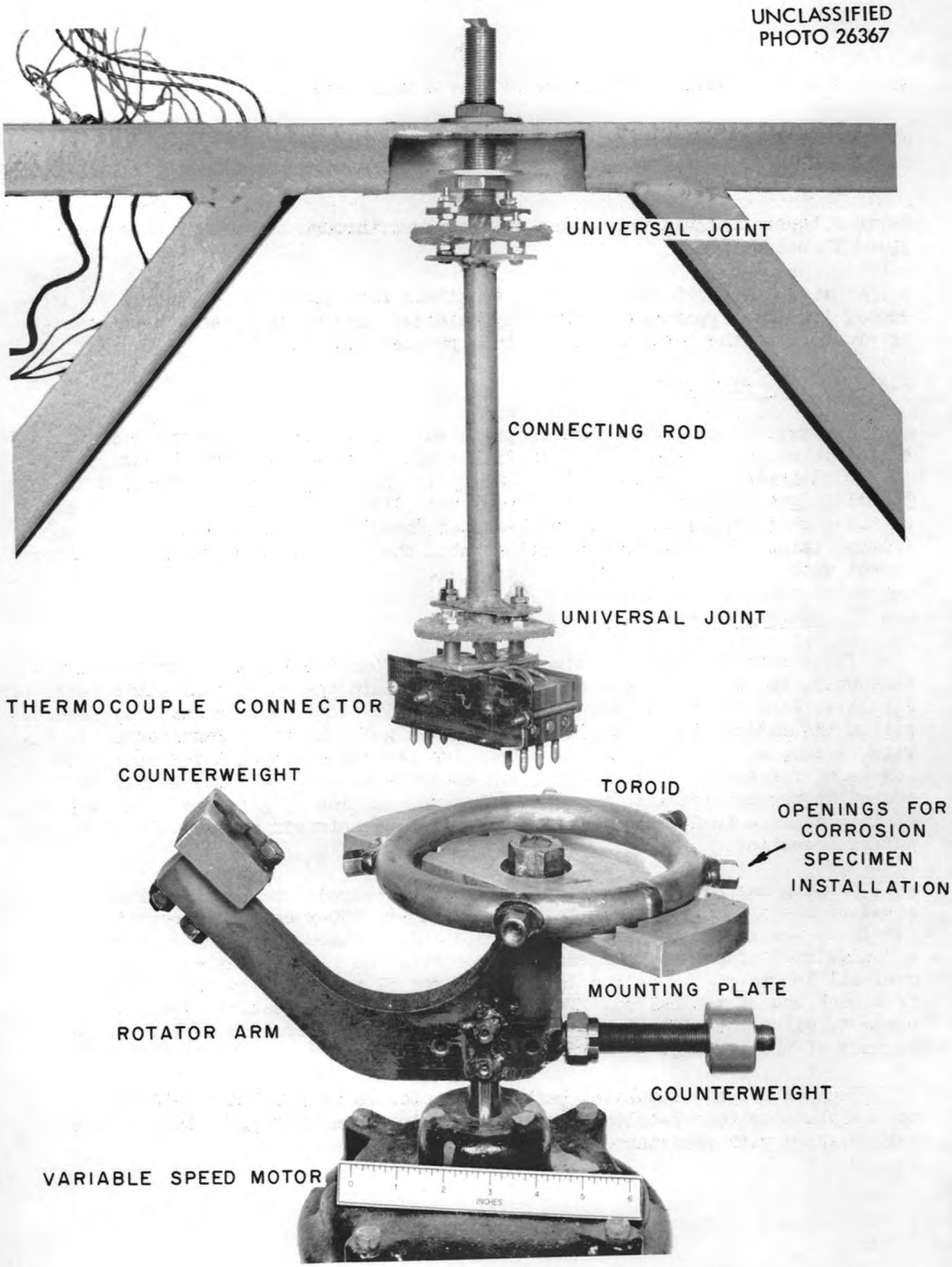

Fig. 1. Toroid Rotator Arm and Mounting Plate

where V = fluid velocity relative to toroid wall, fps

R = radius of toroid, ft

N = motor rotation, fps.

Various constant fluid velocities are achieved through the use of a variable speed DC motor.

For speeds (1725 rpm) required to attain flow rates to 45 fps, it is necessary that the apparatus be properly balanced, and an adjustable counterweight is provided on the rotator arm for this purpose (see Fig. 1).

2.3 Toroidal Flow Test

The type of slug flow that is produced is shown in Figs. 2 and 3 in which a plastic mockup of a toroid, half-filled with water, was used. Fluid flow is in the clockwise direction at 15 to 20 fps. The two pins shown at the 9 and 3 o'clock positions are corrosion specimens (discussed in Sec. 3.5). The first of these photographs shows the well-shaped "head" of the slug and the diffuse, frothy "tail," while the second illustrates the shape of the "head" just after impact with one of the corrosion test pins.

2.4 Toroid Bundle Assembly

The toroid rotator is designed such that four toroids are operated simultaneously, two are installed above and two beneath the horizontal plate (see Fig. 4). Each set of two toroids is wrapped, in order, with a layer of asbestos ribbon insulation, two 13-ft lengths of 20-gauge Nichrome IV resistance heating wire, a single layer of asbestos ribbon insulation, and then three successive layers of reflective aluminum foil and asbestos insulation. The bundle is coated on the outside with a sodium silicate solution to give the outer layer of insulation a hard, durable finish required to maintain mechanical durability during operation.

Heating has also been accomplished with a calrod-type heating element instead of resistance wire. In this case a 115-v, 750-w calrod is bent in a circle to the same diameter as the toroid and is placed between two toroids in a "sandwiched" fashion after each has received one layer of asbestos tape. The over-all length of the calrod is reduced from 32 to 20 in. by cutting 6 in. from each end of the calrod. This does not reduce the heating capacity of the element, since the effective heating length of this calrod is 18 in. (circumference of the toroid).

Each of the two insulated banks of toroids is attached and held firmly to the plate by four U-bolts. In the assembly shown in Fig. 4, the toroids were wrapped with resistance heating wire.

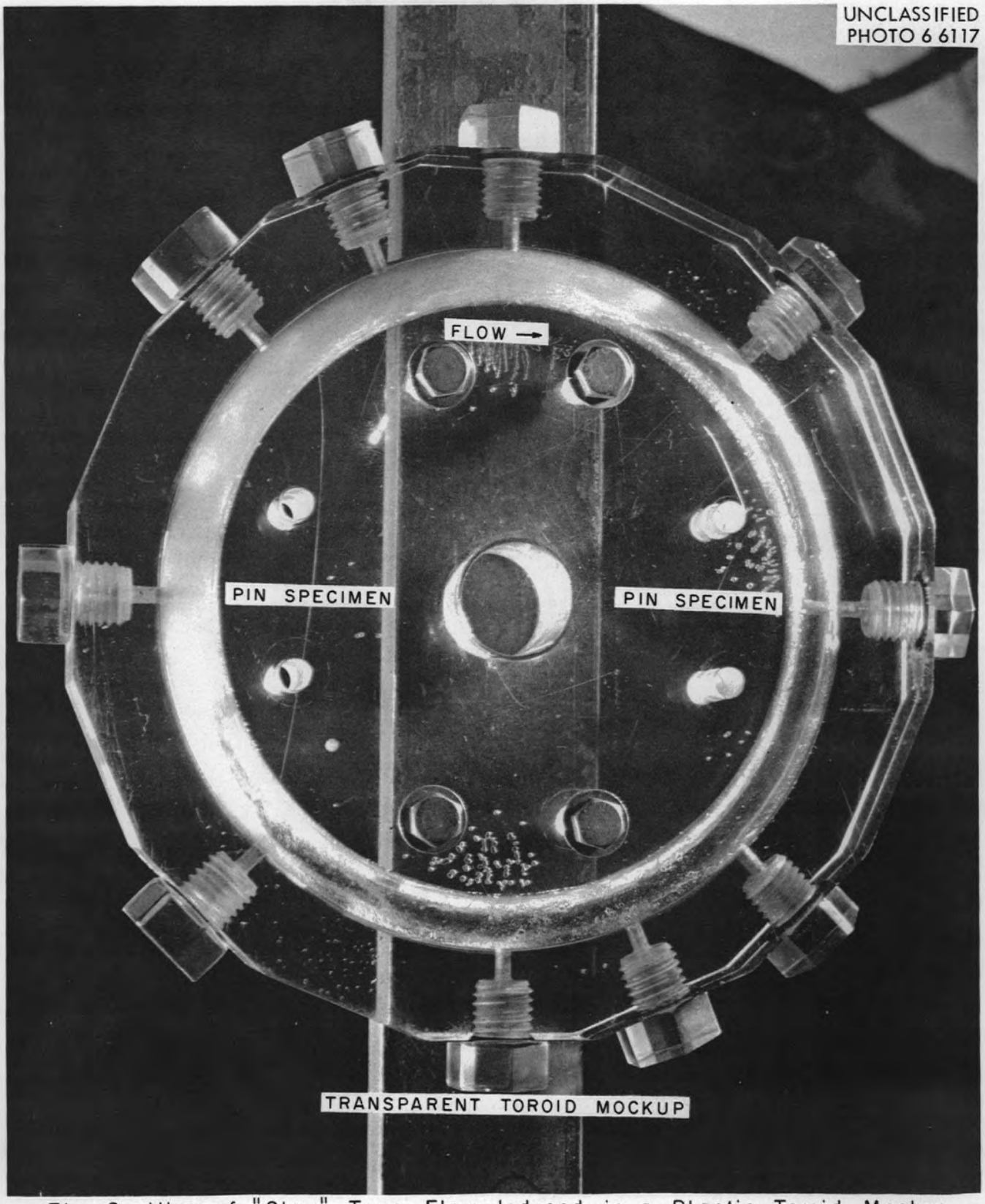

Fig. 2. View of "Slug" Type Flow Induced in a Plastic Toroid Mockup

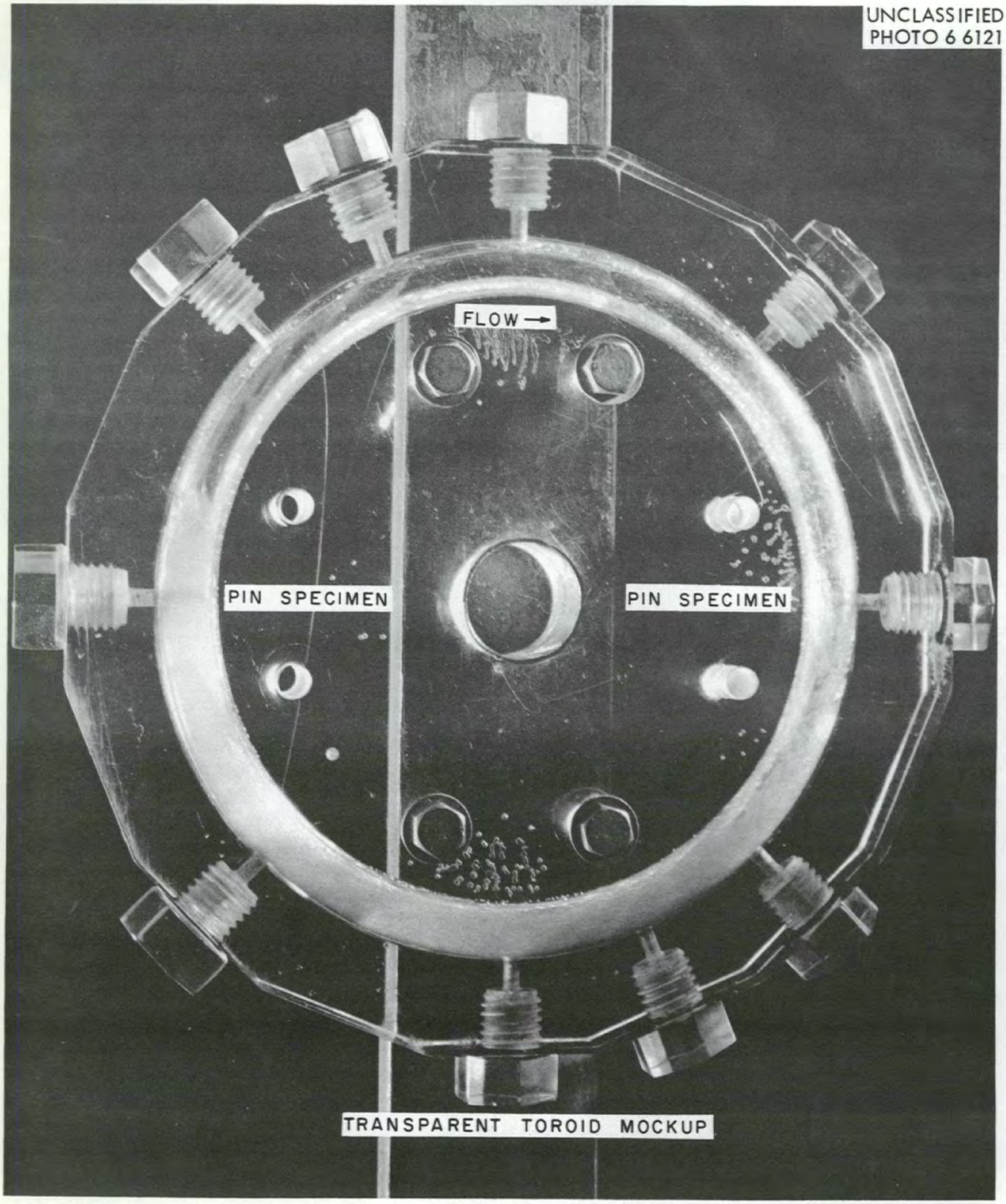

Fig. 3. Effect of Pin Specimen on "Slug" Flow Pattern in Plastic Toroid

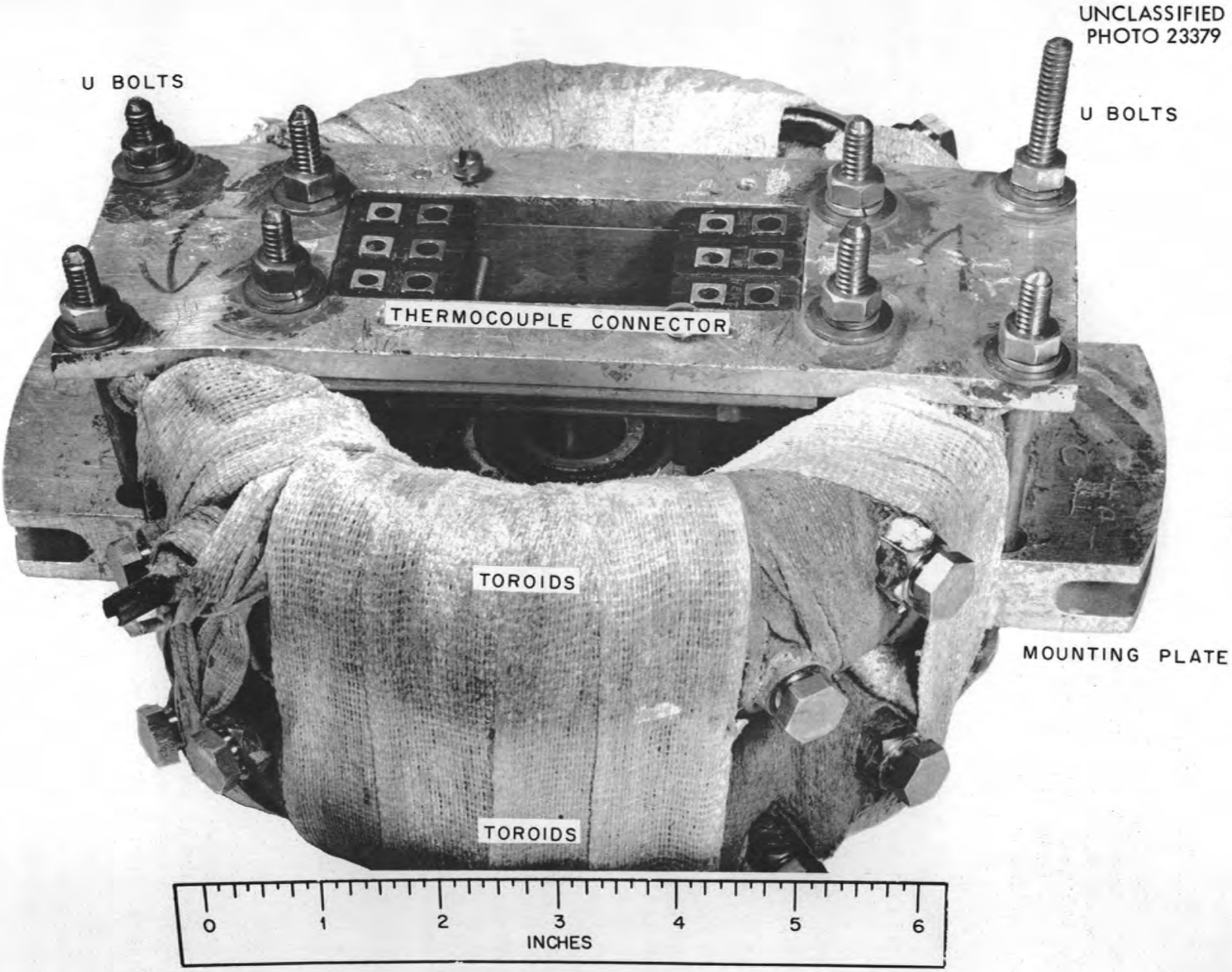

Fig. 4. Assembled Toroid Bundle

2.5 Corrosion Specimens

Four standard 1/4-in. Parker tubing caps are welded on each toroid 90 deg apart around the circumference. A 3/16-in.-dia. hole drilled in the bottom of these caps and through the toroid wall permits the insertion of a corrosion pin specimen into the toroid. The pin specimen is held firmly in a standard 1/4-in. Parker tubing plug by a Teflon bushing slipped on the end of the pin, insulating it electrically from the rest of the apparatus. The pin specimen is 0.125 in. in diameter and 0.950 in. long; the portion exposed to the fluid in the toroid is 0.450 in. long and is not covered by the Teflon sleeve. Figure 5 is a photograph of the pin specimen showing the manner in which it is installed in the toroid. When the plug containing the pin specimen is screwed tightly into the Parker cap, a pressure-tight seal is formed. Corrosion data are obtained from the weight change and visual observation of the corrosion pin specimens after exposure to the circulating fluid in the toroid. In addition, the test solution can be analyzed chemically for corrosion products in order to calculate the extent of attack on the toroid itself.

2.6 "Split" Toroid

Experiments have been conducted with a "split" toroid designed for use with a sleeve-type specimen holder. (Figure 6 is a photograph of an unassembled "split" toroid and sleeve-type specimen holder.) This toroid is fabricated in two halves with threaded couplings on each end to permit joining the two. The sleeve holder is designed to contain and expose a coupon-type corrosion specimen in the test solution or slurry. Use of the sleeve holder permits specimens of various configurations and geometries to be included in the toroid. An additional advantage of the "split" toroid is that the interior surface of the toroid can be examined as desired. It should be noted that the use of threaded couplings causes it to be slightly oblong owing to the straight sections required at each coupling. However, this slight deviation from a circle does not appear to affect the flow, as indicated by comparison of the experimental data obtained with the "split" toroid and the circular welded toroids.

2.7 Temperature Measurement

The temperature of the toroid during circulation is measured with iron constantan thermocouples which may be resistance-welded or mechanically attached to the outside metal wall of the toroid before it is wrapped with the asbestos tape. Another and probably a more accurate method of measuring the fluid temperature is to install a thermocouple in thermowells projecting into the toroid through one or more of the openings normally used to insert pin specimens. A small tube sealed at one end is extended through the hole in the seal plug and is welded to it at the top (see Fig. 7). If desired, the thermocouple junction can be bonded in the seal weld at the bottom of the thermowell. Regardless of the method of attachment, the couples are connected to the female half of a set of six thermocouple connectors which are retained in a box-type

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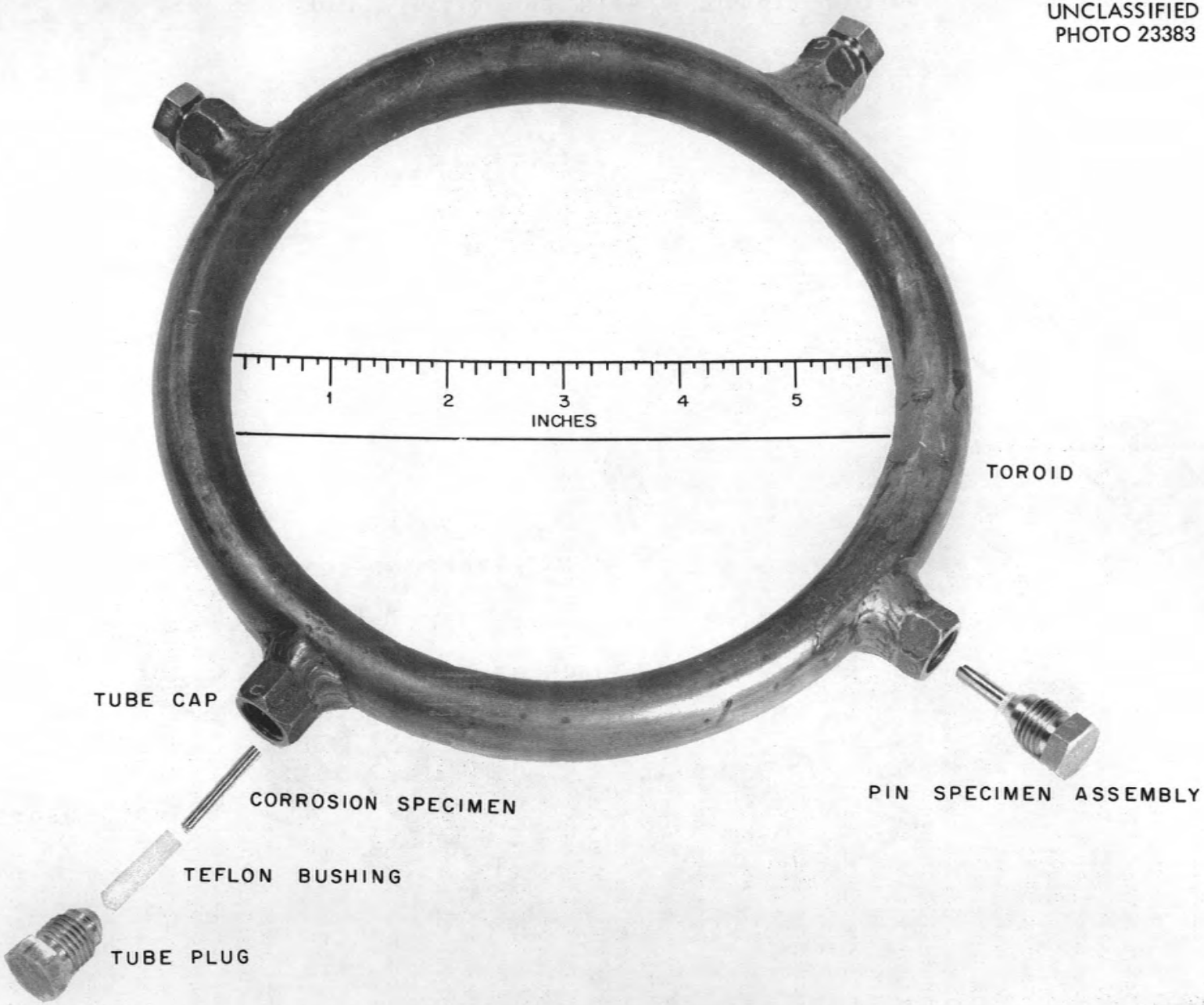

Fig. 5. Toroid Pin Corrosion Specimen Assembly

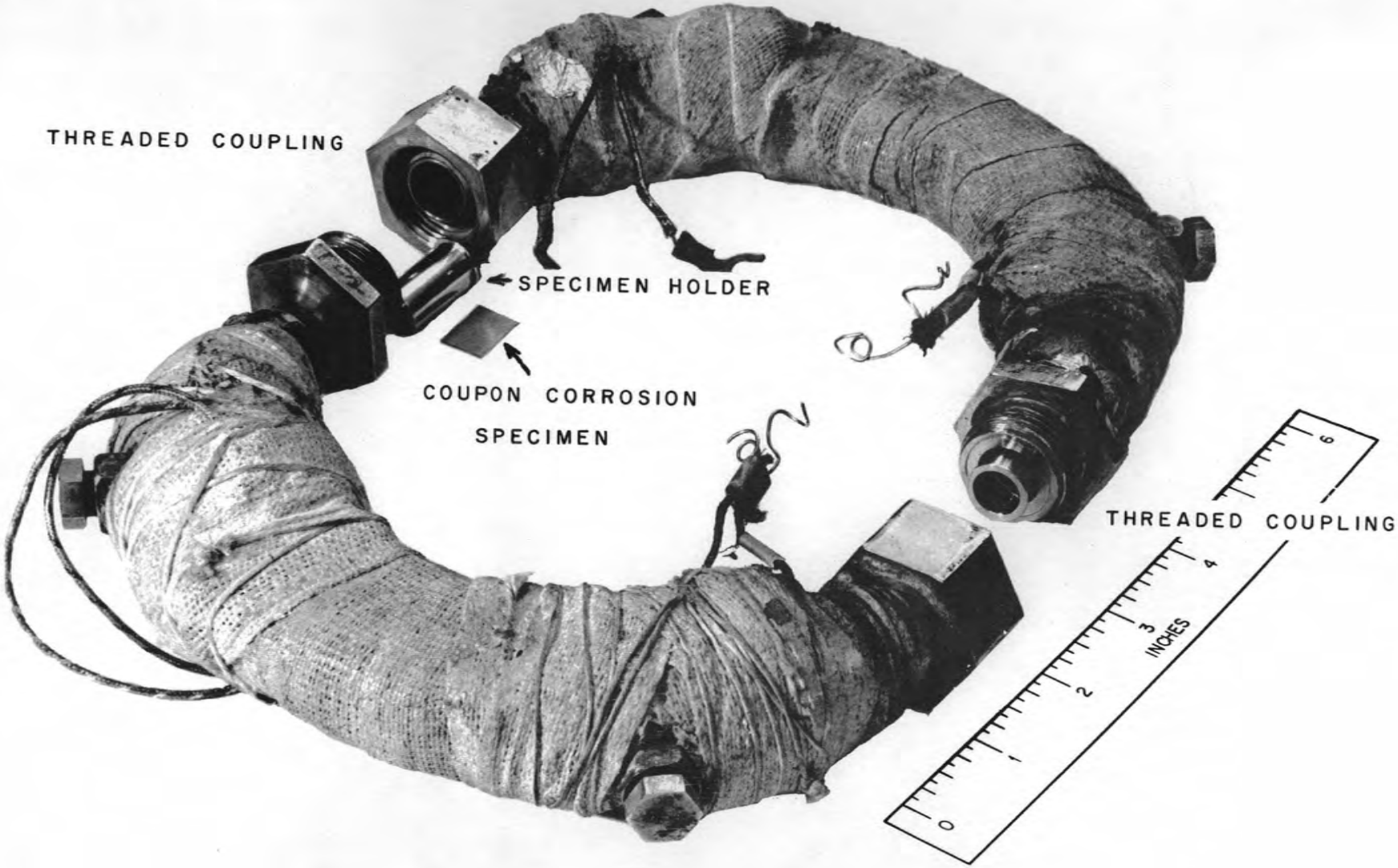

Fig. 6. "Split" Toroid and Sleeve Sample Holder

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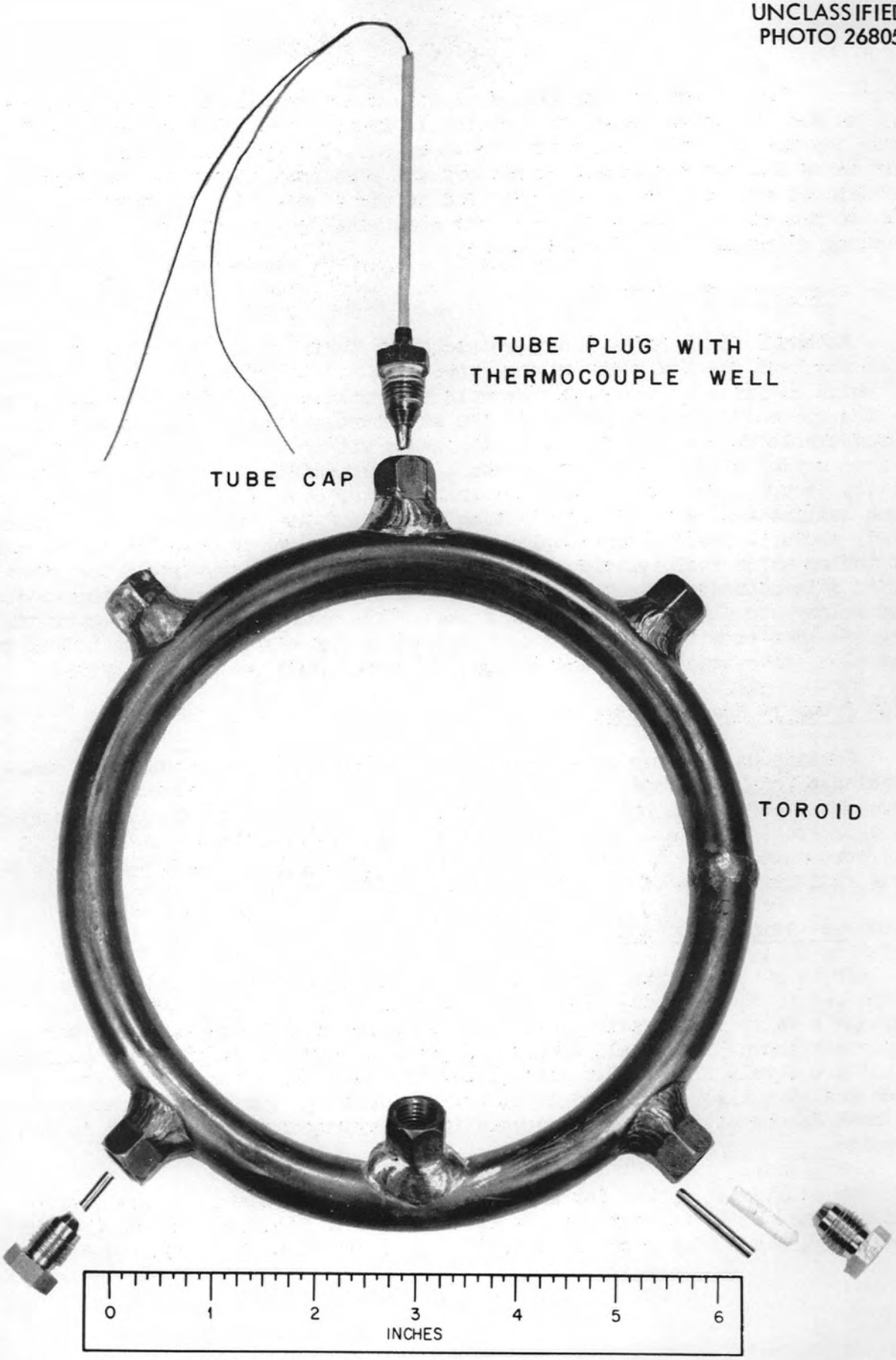

Fig. 7. Toroid Assembly Showing Thermocouple Well

holder. The holder rests on top of the insulated toroid bundle and is held by the U-bolts which secure the toroids to their plate. The holder, complete with the thermocouple connectors, is shown bolted in position in Fig. 4. The mates for the six female connectors are also contained in a box-type holder and are located at the lower end of the connecting rod shown in Fig. 1. Two of the six connectors are used for electrical power connections to the heating elements in the toroid bundle.

2.8 Connecting-Rod Assembly

Although the toroids do not rotate about their own axes during operation, both they and the lower end of the connecting rod travel in a circle, the radius of which is fixed by the crank throw in the rotator arm. Since the upper end of the connecting rod is bolted to the structural frame of the apparatus, a considerable degree of flexibility is needed within the rod to permit the described motion without bending the shaft or overloading the motor. This flexibility is achieved through two universal joints, each of which is fabricated from laminated-fiber, conveyor-belting material. One joint is located immediately above the male thermocouple-connector holder and is attached to a section of tubing which encloses the thermocouple leads and heater wires. The other joint interconnects this tube to another tube which is threaded on the outside and bolts securely to the mounting frame. This entire assembly is shown in Fig. 8. Heater wires and thermocouple leads are passed through the bolted tube and along the structural frame to the instrument panel and power supply.

2.9 Pressure Measurements

Continuous pressure measurements may be taken during operation by seal-welding a length of capillary tubing to one of the 1/4-in. Parker plugs through which a small hole has been drilled. The capillary tube is connected to a pressure gauge and/or transmitter through a valve manifold attached to the structural frame. The capillary tube is coiled to minimize deflection and thus fatigue failure of the tube as shown in Fig. 9.

2.10 Gas Addition to a Toroid

It is often desirable to obtain corrosion data with various gaseous atmospheres in the toroids. A known gas overpressure can be added to a toroid through a valve manifold if the toroid is equipped with the capillary tubing described above. For small amounts of gas, the toroids (without a capillary tube) are merely flushed (at atmospheric pressure) with the desired gas and then sealed. Also, estimated overpressures of oxygen can be obtained by the thermal decomposition of a known quantity of hydrogen peroxide added to the toroids.

An additional method for adding a measured overpressure of any desired gas to a toroid is by means of the device shown in Fig. 10. One of the pin specimen holders (described in Sec. 2.5) is replaced with a modified Parker

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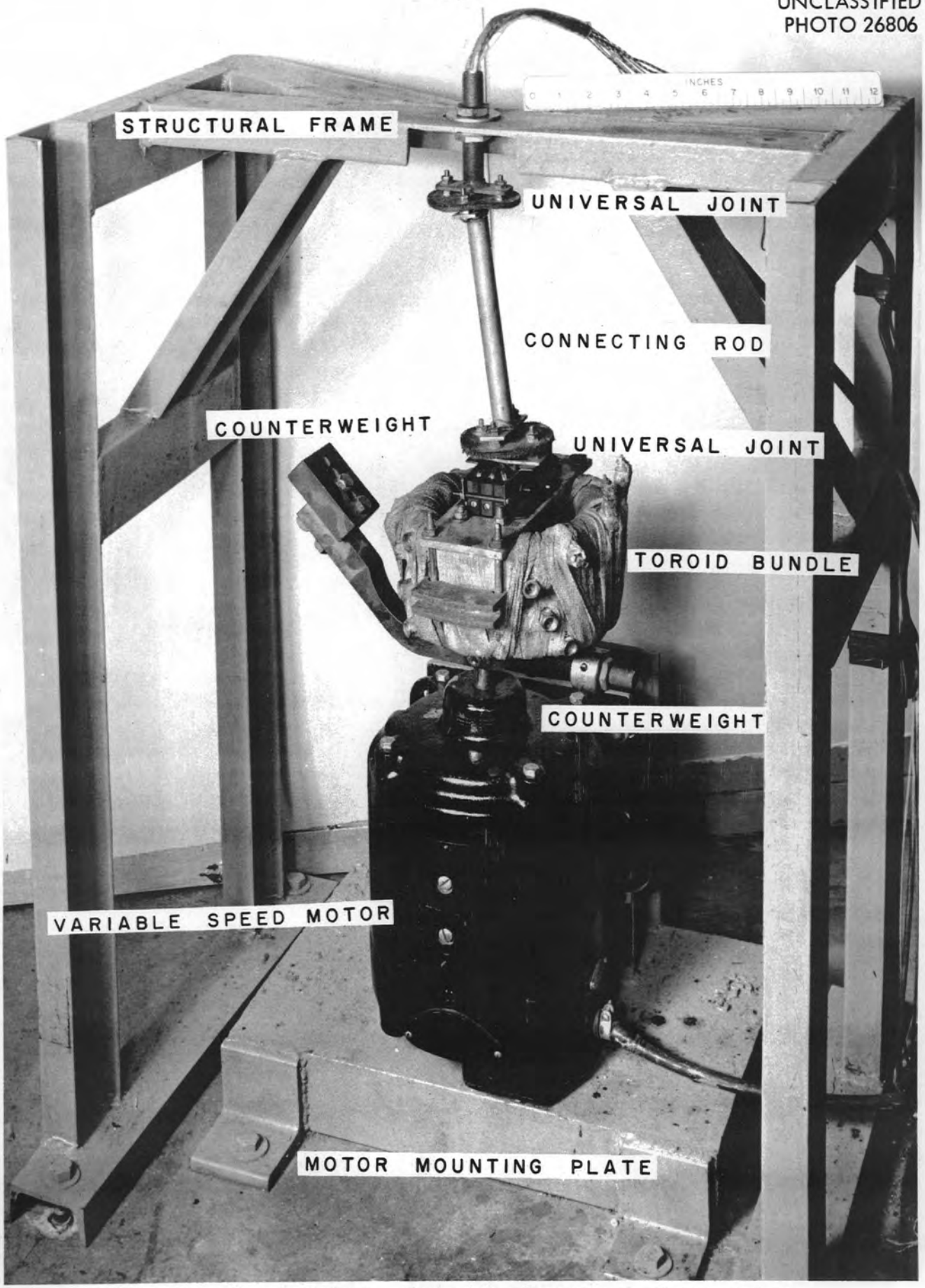

Fig. 8. Assembled Toroid Rotator Apparatus

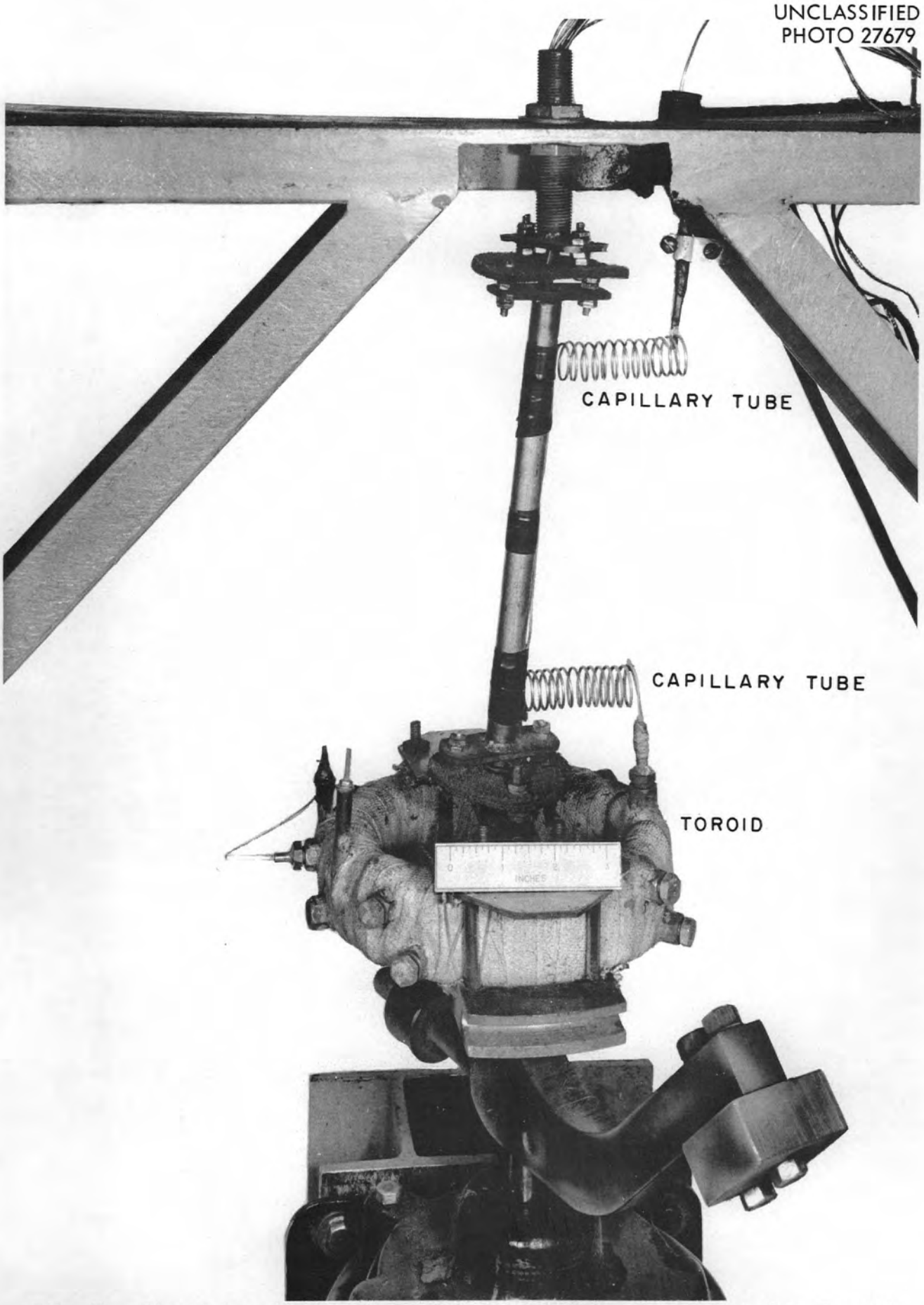

Fig. 9. Pressure Measuring and Transmitting Layout for Toroid

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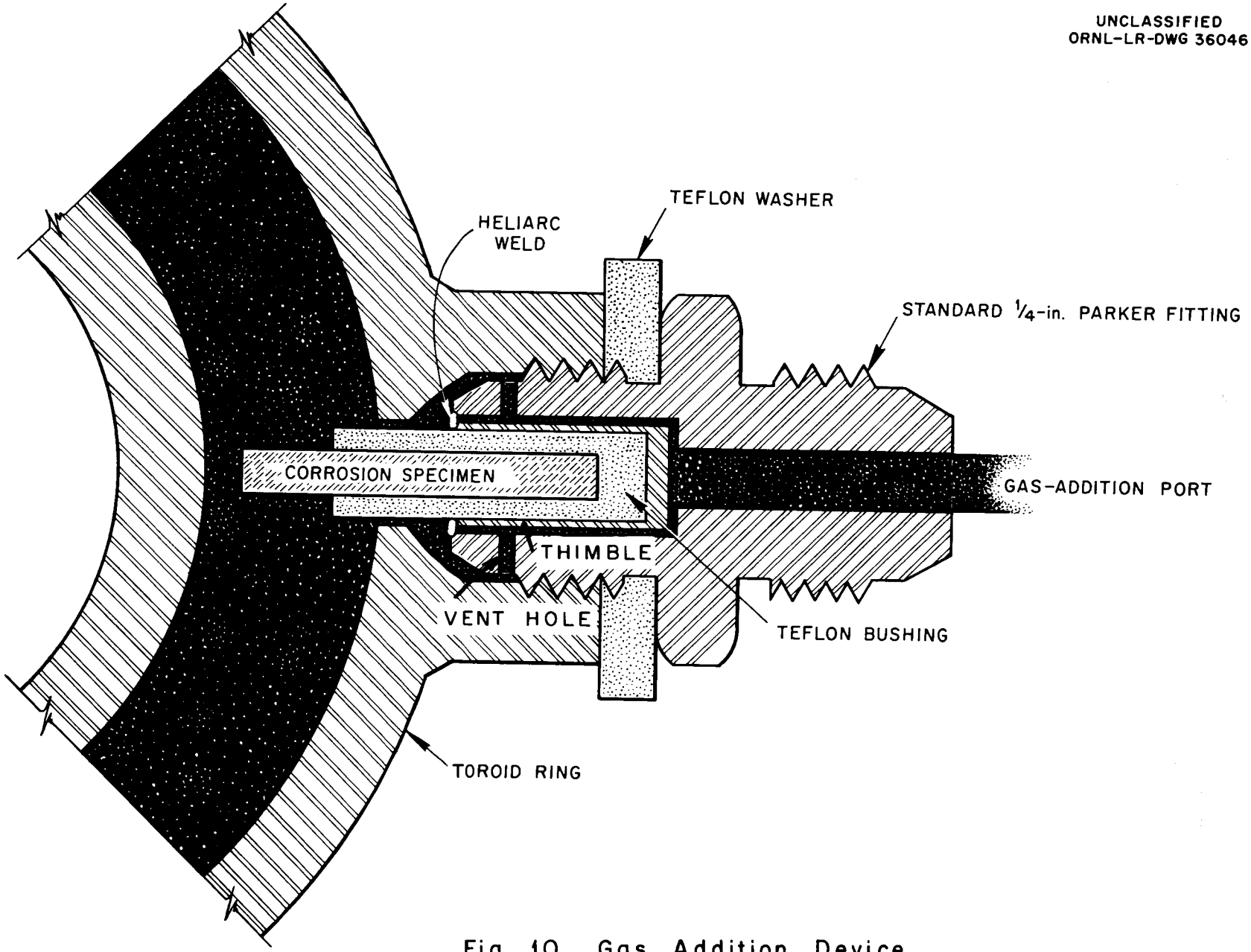

Fig. 10. Gas Addition Device

tube fitting. A small vent hole is drilled radially through the threaded region of the fitting. A metal thimble is seal-welded at the coned end of the fitting and the pin specimen, in its Teflon bushing, is inserted into the thimble. This thimble prevents leakage past the Teflon bushing through the vent hole.

A gas connection is made to the fitting at the outside end. The fitting is then tightened enough to effect a seal to the outside by means of a Teflon washer between the fitting and toroid plug. However, the fitting is not tightened sufficiently to seal at its coned end at the inside of the plug. After adding the desired gas pressure, the fitting is tightened further until a leak-tight seal is made at the coned end. The gas connection can then be broken.

2.11 Framing and Shielding

The structural framing for the rotator is fabricated from 2-in. channel iron. The primary design consideration involved the use of a frame capable of holding the upper end of the connecting rod stationary during high rotational speeds (up to 1725 rpm). In addition, experience has shown that the motor mounting plate should not be attached to the toroid frame but must be independently supported to reduce rotational vibrations of the toroid assembly. The entire toroid rotator assembly is contained within shielding designed to contain the apparatus in case of mechanical failure of any part of the assembly. The shielding can be opened so that the toroids can be removed and replaced.

3. EQUIPMENT DESCRIPTION

3.1 Motor

General Electric Thy-mo-trol d-c shunt motor, 1/2 hp 230-field volt, 140 armature volts, 3.3 armature amperes, 86 to 1725 rpm continuous rating, model No. 5BC76AB299B, series YMC.

3.2 Variable-Speed-Drive Mechanism

General Electric Thy-mo-trol drive unit, model No. Cr-7507-F170G18, complete with control panel and control station consisting of push buttons and speed-adjusting potentiometer. The drive converts 220-v, 60-c, a-c power to d-c by rectification and supplies power to the armature and the field of the d-c shunt motor controlling the armature voltage so that speed variation can be obtained.

3.3 Assembly and Component Drawings

In the following list are drawings pertinent to the design of the toroid rotator installation:

Part	Drawing No.
Rotator arm	TD-D-4769
Rotator plate	TD-D-4770
Toroid (circular)	TD-D-4770
Toroid (split)	TD-D-4340
Plug and pin specimen	TD-D-4770
Connecting rod	TD-D-4769
Thermocouple connector	TD-D-4770
Sleeve sample holder and specimen	TD-C-4771
Control panel layout	TD-D-4678
Wiring diagram	TD-D-4679

4. INSTRUMENTATION

4.1 Temperature Recording and Control

As outlined in Sec. 2.7, thermocouples installed on the toroids permit continuous temperature measurements during operation. The thermocouple readings of each toroid are plotted continuously on a Honeywell multiple-point recorder. In addition, one thermocouple from the toroid bundle (four toroids) is routed to a calibrated Simplitrol controller. The Simplitrol maintains a predetermined operating temperature within approximately $\pm$ 5°C by automatically opening and closing a relay in the heater power supply circuit. A 115-v, 15-amp Variac is included in the heater circuit to permit coarse manual adjustment of the heater power.

4.2 Speed Variation and Measurement

Constant motor speeds over the range of 86 to 1725 rpm are obtained by manipulation of the speed-adjusting potentiometer contained in the control station of the Thy-mo-trol drive. However, the drive does not compensate for a-c supply-line voltage fluctuations, and the motor speed varies slightly as the supply voltage varies. To detect these speed variations during continuous operation, periodic visual checks of the rotational speed are made with a Strobotac.

4.3 Pressure Indication and Recording

Continuous pressure indication and recording are obtained with the toroid capillary tubing installation described in Sec. 2.9. A Swartwout pressure transmitter and strip-chart recorder are the instruments used to indicate and record this data.

4.4 Control Panel

Figure 11 is a photograph of the control panel from which the five rotator positions are operated. The Honeywell multiple-point recorder which provides continuous temperature measurements is shown in the upper left of the panel. (The second recorder shown in the photograph is not used for the rotators.) On the upper right is a strip chart for continuous pressure indication and recording for one rotator position. Directly beneath the strip chart are six Simplitrol controllers which maintain toroid operating temperatures. Normally one controller is used per rotator position, and the sixth instrument is an installed spare. The variable-speed-motor control stations, the heater and motor starting switches, and the Variacs for the heating circuits are shown in the center sections of the panel, while the portable Strobotac is pictured in the lower right-hand corner.

5. FABRICATION AND ASSEMBLY COSTS OF TOROID ROTATORS

Table 1 lists the costs incurred in the fabrication and assembly of five toroid-rotator positions at ORNL during mid-1955. All craft labor costs, regardless of the type, are charged at a rate of $5 per hr.

Table 1. Fabrication and Assembly Costs of Five Rotator Positions

Item	Total No. of Units	Total Cost		Unit Cost per Rotator Position	
		Material	Labor	Material	Labor
D-C motor and Thy-mo-trol drive	5	$1,250		$250	
Variac 115-v, 15-amp	5	250		50	
Simplitrol controller	5	750		150	
Multipoint recorder	1	1,500		300	
Strobotac	1	150		30	
Pressure transmitter and recorder	1*	240*		240*	
Frames and shields	5	60	$ 800	12	$ 160
Rotator apparatus (excludes toroids)	5	50	1,000	10	200
Toroids and specimens	20	105	3,500	21	700
Control panel (includes frame, conduit, wire, etc.)	1	100	2,800	20	560
Subtotals		$4,215	$8,100	$843	$1,620
TOTALS		$12,315		$2,463	

* Only one position is equipped with pressure instrumentation at present. Cost not included in totals.

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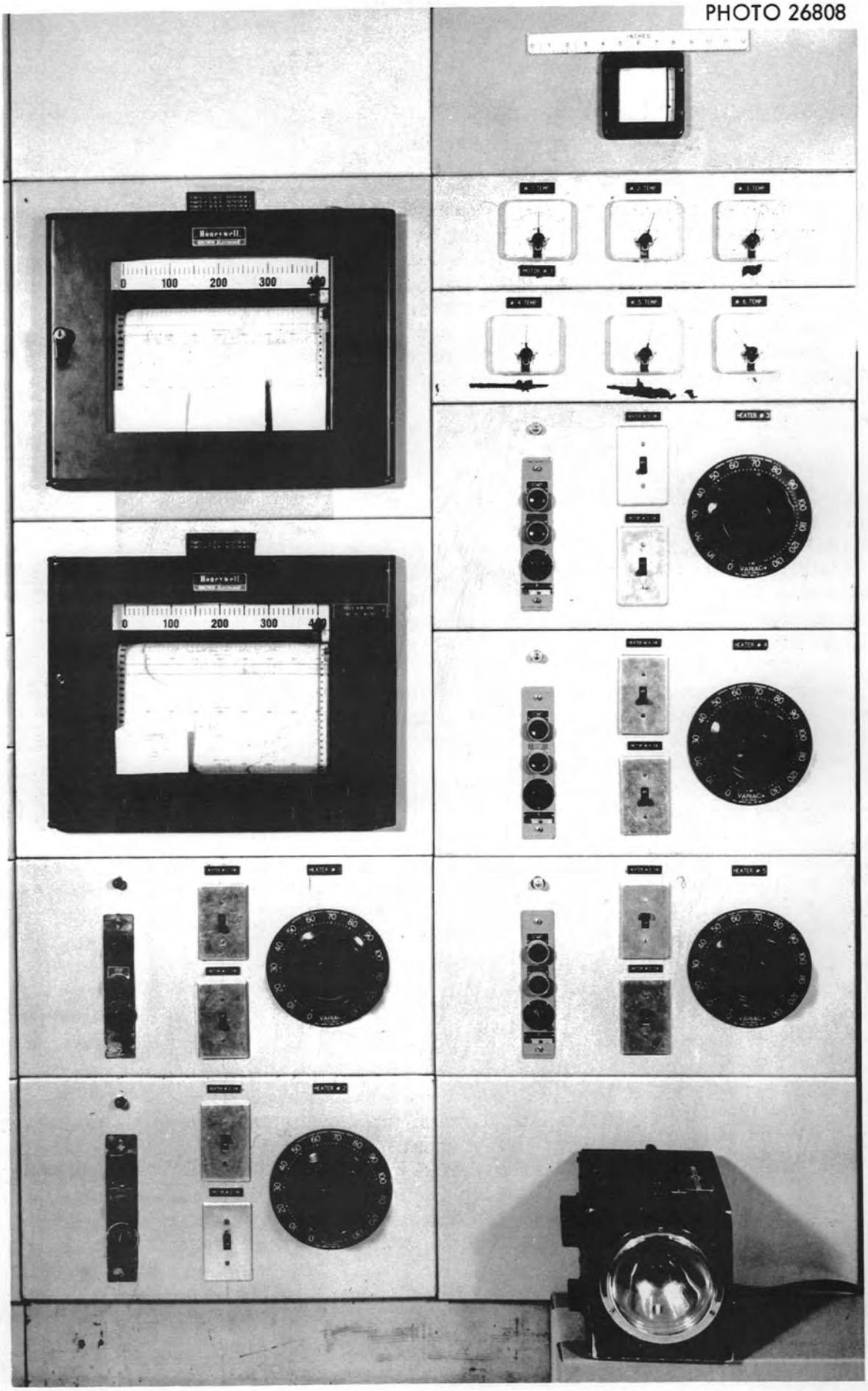

Fig. 11. Instrument Control Panel for Five Toroid Rotator Positions

6. DESIGN LIMITATIONS

6.1 "Slug" Type Flow

One problem associated with the use of toroids for dynamic corrosion tests is the interpretation of results based on the "slug" flow that exists during circulation. However, this is not a serious problem since the toroids are not intended to replace any of the existing methods of studying dynamic corrosion. Their role is complementary to the existing techniques of static and dynamic corrosion test systems. Furthermore, operational experience has shown that the corrosion data obtained from toroids exhibit trends which correlate favorably with comparable data obtained from dynamic loop studies.

6.2 Speed Limitations

While high-speed operation (above 30 fps circulating velocity) is not a design limitation of the rotator, dynamic balance becomes an important consideration. The size and position of the counterweights on the rotator arm must be adjusted to ensure that the entire apparatus is completely balanced, thereby eliminating excessive vibration which will cause mechanical failure and serious damage to the equipment. Assuming that care is taken to achieve dynamic balance, the toroids can be rotated at the maximum operational speed of the motor (1725 rpm), which gives a fluid velocity of approximately 45 fps.

As an alternative to attain higher circulating velocities, toroids of a larger diameter could be used. This would create additional mechanical and circulation problems, however, and some of the advantages of the small-scale equipment would be sacrificed.

6.3 Temperature Measurement

Obtaining the true temperature of the fluid circulating in a "slug" fashion in the toroid is a difficult problem. Use of the plug thermocouple well with the thermocouple junction embedded in the bottom of the well probably results in measurements accurate to within a few degrees.

7. OPERATIONAL EXPERIENCE

To date, five toroid rotators have been in service for approximately three years. The toroids have been used for dynamic corrosion studies with uranyl sulfate solutions, but they have proved most valuable in evaluating the corrosion and/or erosion of thorium and thorium-uranium oxide slurries of interest to the Aqueous Homogeneous Reactor Program. Continuous runs ranging from 50 to 1350 hr have been accomplished with circulating velocities up to 30 fps, temperatures ranging from 100 to 300°C, and pressures up to 1500 psia. However, experimental considerations make the optimum length of the runs range from 200 to 300 hr, and most of the runs to date have been for these lengths of time.

Maintenance has involved chiefly a close inspection of the apparatus after each run. The bearing in the horizontal rotator plate must be lubricated with a high-temperature grease, and thermocouple leads are thoroughly inspected for insulation wear and short-circuiting. Operating experience has shown that the calrod heating elements are more serviceable than the resistance heating wire, and their use permits the operating temperature of the toroid bundle to be attained more readily during startup without fear of burning-out the element.

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