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Research and Development Report

ARC MELTING IN THE TUNGSTEN ELECTRODE FURNACE

by

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D. E. Williams and H. L. Levingston

ABSTRACT

An arc furnace is described which employs a non-consumable tungsten electrode and a water-cooled copper hearth. It has been used successfully for melting refractory metals and alloys. The furnace is equipped with a vacuum system, an inert gas supply, and an 800-ampere direct-current power supply.

INTRODUCTION

The development of nuclear reactors, missiles and high speed aircraft hasprompted an interest in the high-melting metals. Unfortunately, these metals present difficulties in melting and fabrication. Because of their affinity for oxygen, they must be melted in a vacuum or under an inert atmosphere. Most of the ordinary refractory crucibles are attacked by these metals in the molten state, and some are mechanically weak at the temperatures involved. Many of these metals and their alloys can be prepared by the methods of powder metallurgy, but the products made by this process do not fill all needs. As a consequence, research metallurgists have made much use in recent years of the kind of furnace described in this report.

HISTORICAL REVIEW

The idea of an arc furnace is not new. In 1905, von Bolton (1) designed and built an arc-furnace with a water-cooled hearth for melting tantalum. Little more attention was given to the possibility of using this type of furnace until 1939 when Kroll designed equipment for melting titanium. Kroll modified von Bolton's design by substituting thoriated tungsten for the tantalum electrode tip. During, and especially after World War II, an increasing number of investigators found use for such furnaces until they have become relatively common laboratory equipment. They have been used for melting titanium (2, 3, 4, 5, 6), zirconium (7), molybdenum (5), chromium (8), tungsten (9) and other metals.

DESCRIPTION

The furnace described in this report is shown in Fig. 1. Its essential parts are the melting chamber, the movable electrode, the vacuum pumping system with its accessory gauges and valves, and the power unit. A line from a tank of helium enters the pumping system near the chamber. Water supply lines run to the individually jacketed top, bottom and sides of the melting chamber and to the electrode shaft.

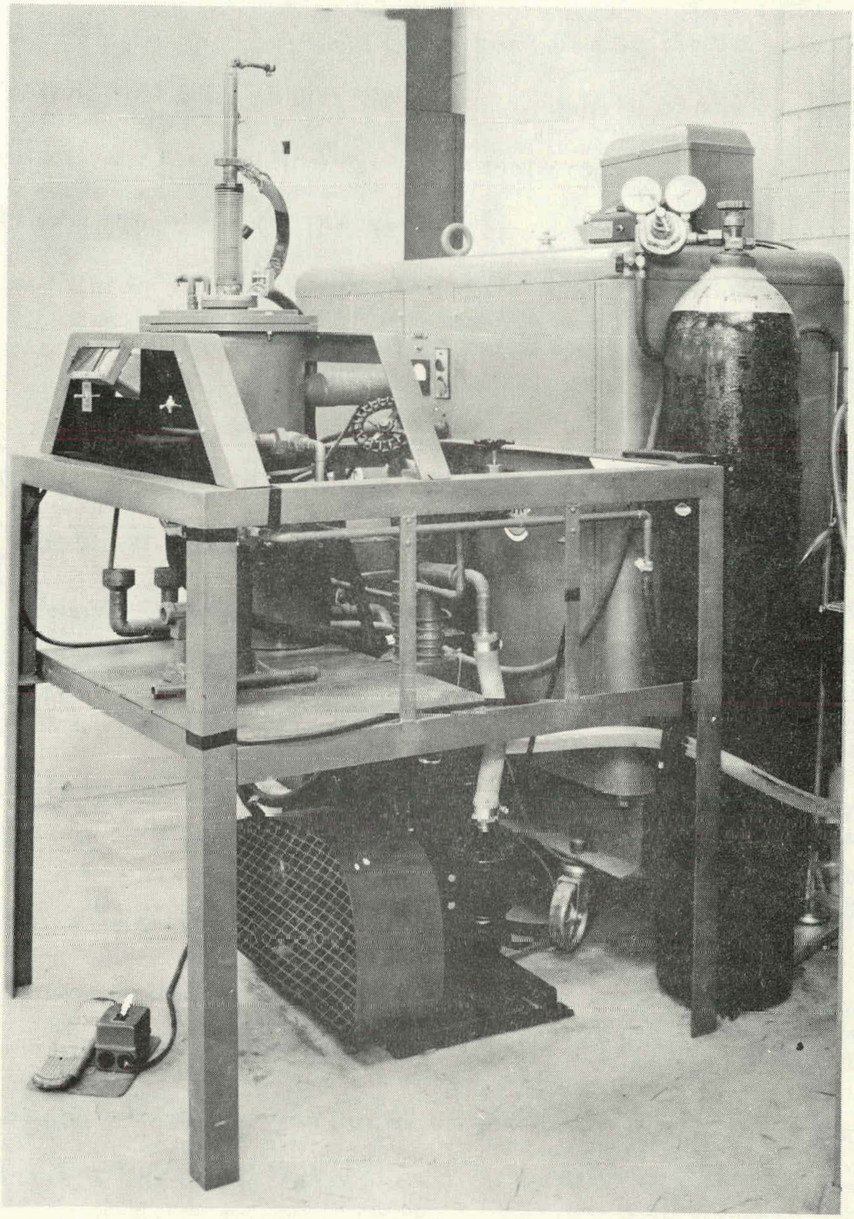

Fig. 1 - A Tungsten Arc Furnace for Laboratory Melting.

The melting chamber is shown in Figs. 2, 3, 4. The apparatus depicted in these figures differs from the equipment shown in the photograph in Fig. 1 by having a ball and sliding shaft arrangement instead of a metal bellows at the entrance of the movable electrode into the chamber. Either arrangement gives satisfactory results. The bellows is a simple device but occasionally develops leaks where it is soldered to other parts and may crack at a fold. The ball and sliding shaft are more complicated to construct but require less maintenance and are easier to manipulate during melting.

Figure 2 shows the cylinder, or barrel of the melting chamber, and its attachments. The cylinder is made of copper tubing about 8 in. inside diameter and has flanges for the attachment of the top and bottom plates shown in Figs. 3 and 4, respectively. The pumping system may be isolated from the melting chamber by the vacuum valve when helium is to be admitted. The hydraulic jack is used to hold the lower plate (Fig. 4) against the lower flange of the barrel.

The top plate is shown in Fig. 3. It is attached to the barrel by 6 bolts through holes near the rim. A rubber gasket makes the joint vacuum tight.

An important component of the top section is the movable electrode that passes through the center of the plate. By means of the sliding shaft and ball combination, the operator can move the tungsten tip of the electrode to any desired point in the melting chamber. Much of the heat that enters the electrode tip is removed through the water-cooled shaft.

Figure 4 shows the bottom plate which carries the hearth or crucible and is also the negative electrode. It is insulated from the barrel by a

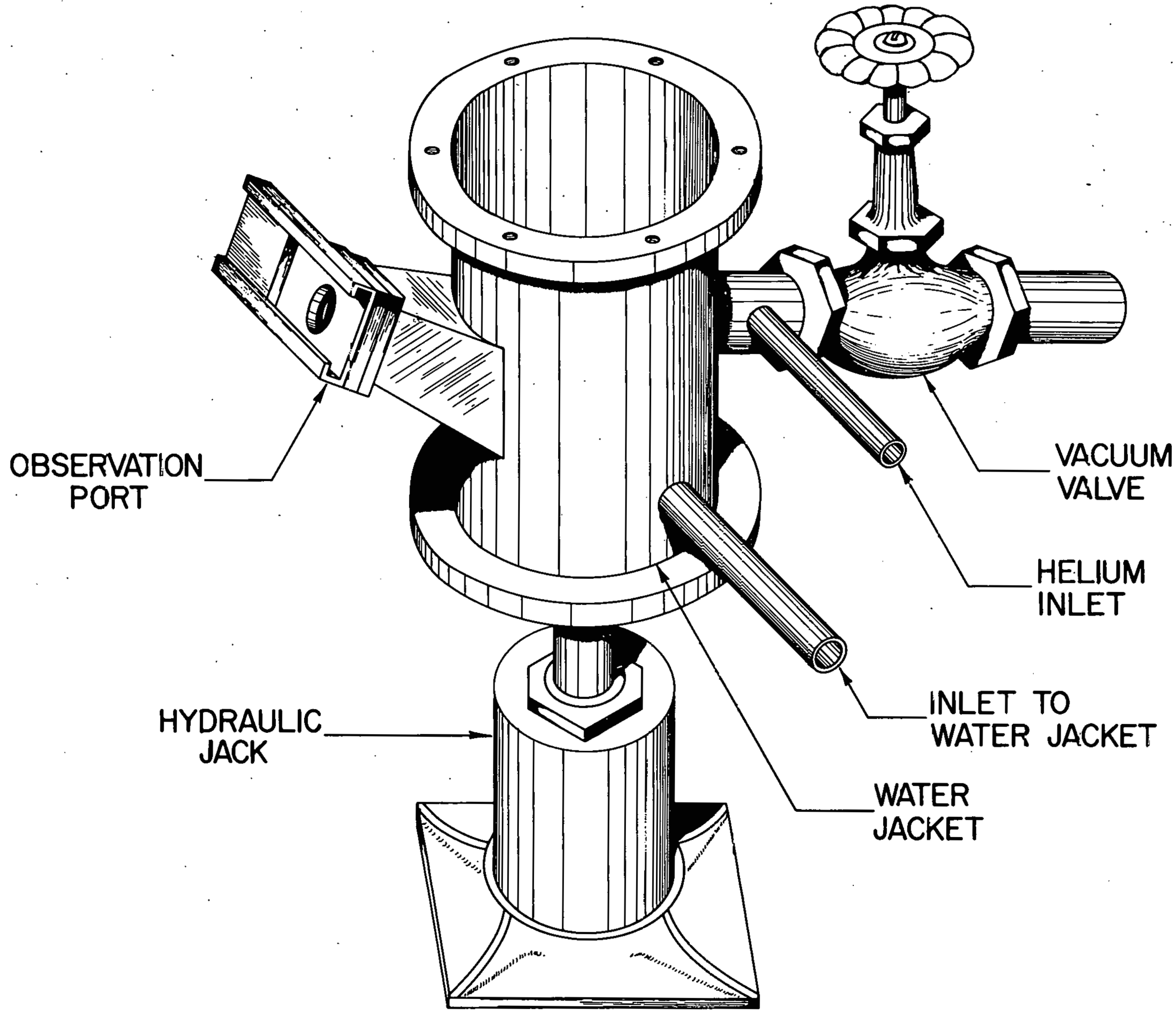

Fig. 2 - The Barrel of the Melting Chamber.

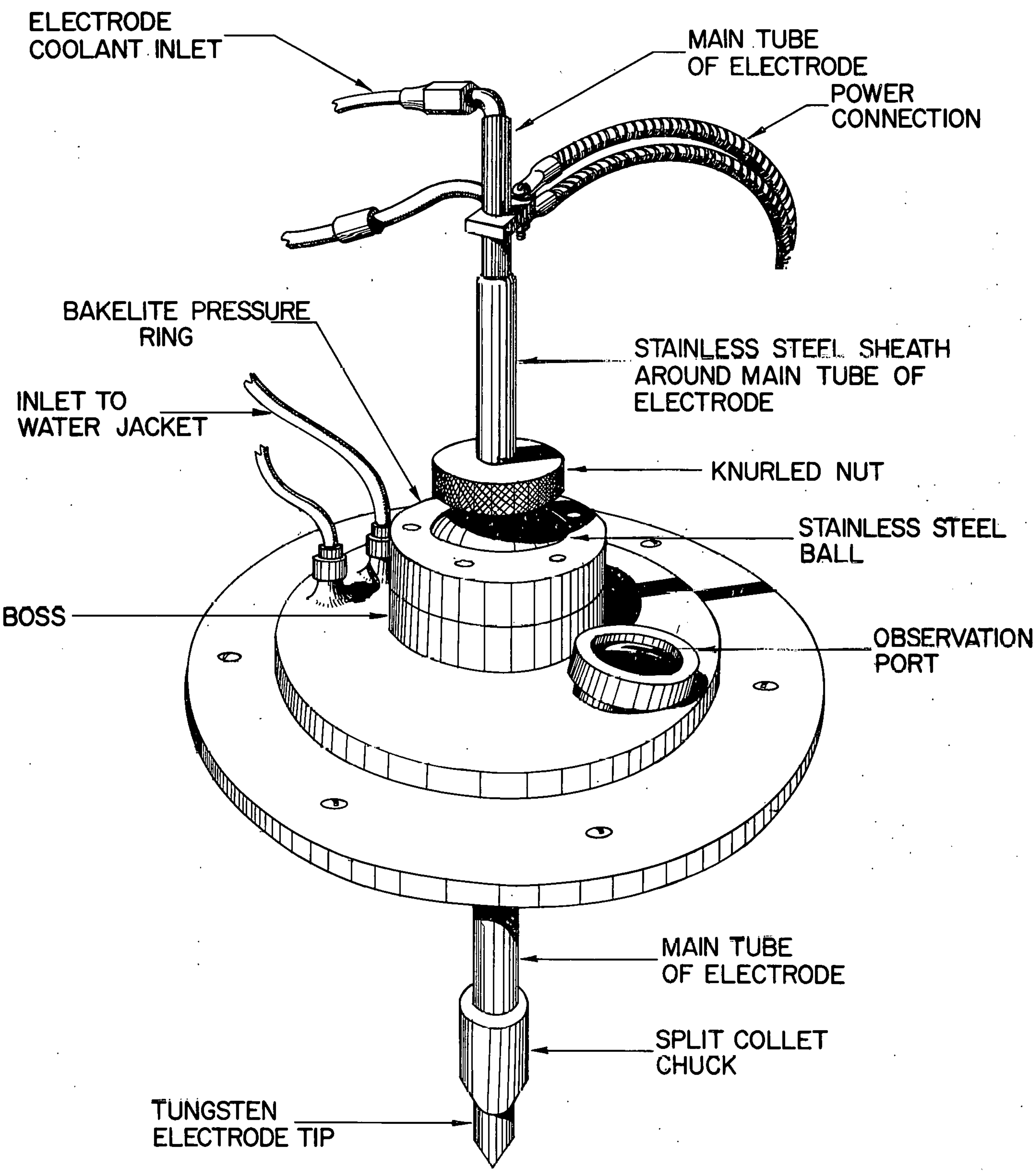

Fig. 3 - The Top of the Melting Chamber.

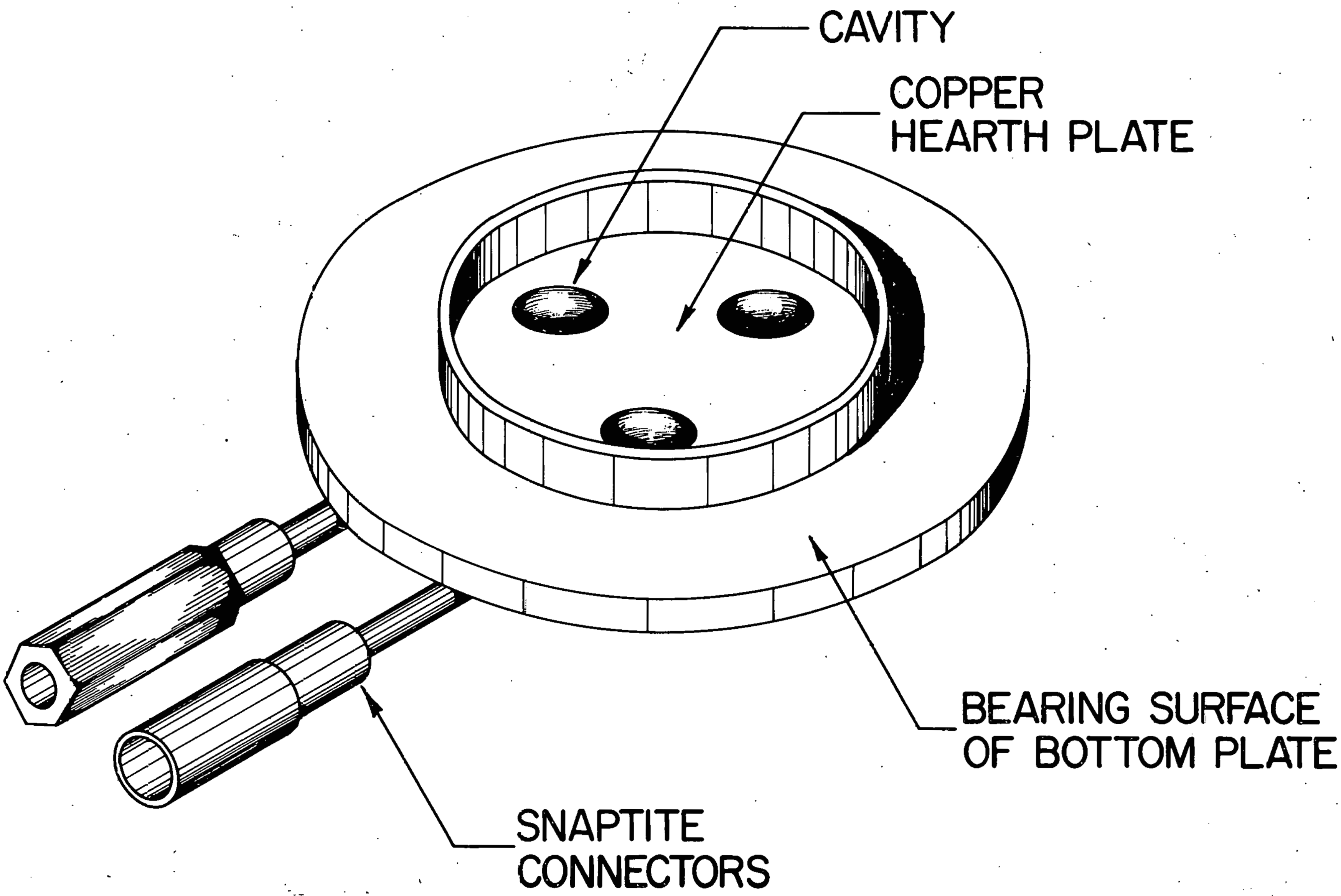

Fig. 4 - The Bottom of the Melting Chamber.

1/2-in. -thick bakelite ring which occupies a position between the lower flange of the barrel (Fig. 2) and the bearing surface of the bottom plate. The bottom plate and the ring assembly are held firmly against the flange on the barrel by the hydraulic jack shown in Fig. 2.

The crucible consists of a 1/2-in. -thick plate of copper in which three cavities, each about 1/4-in. deep by 1 3/4-in. in diameter, have been formed. A space between the lower surface of the hearth plate and the main plate serves as a water jacket to cool the hearth plate. Water lines are attached by Snaptite connectors. Electric power is connected to the plate by a plug and jack arrangement not shown.

An alternative crucible assembly was constructed in which the hearth plate can be easily removed from its water jacket. The plate rests on top of the jacket which is raised and lowered by a pneumatic piston instead of the hydraulic jack. A water-tight seal is made by an O-ring between the hearth plate and the top flange of the water jacket. This arrangement permits the rapid exchange of hearth plates of different cavity design and facilitates cleaning and maintenance.

Additional details of the construction of the sliding shaft and ball mechanism are shown in Fig. 5. The polished stainless steel sleeve surrounding the electrode slides through the polished stainless steel ball and is guided by the three O-rings. These O-rings are held in position by the brass cylindrical spacers that, in combination with the knurled nut, serve to compress the rings slightly and force them to bear firmly on both the shaft and the interior of the ball so that the combination is vacuum tight. Rings and shaft are lubricated with silicone vacuum grease. The ball rests in a contoured cavity

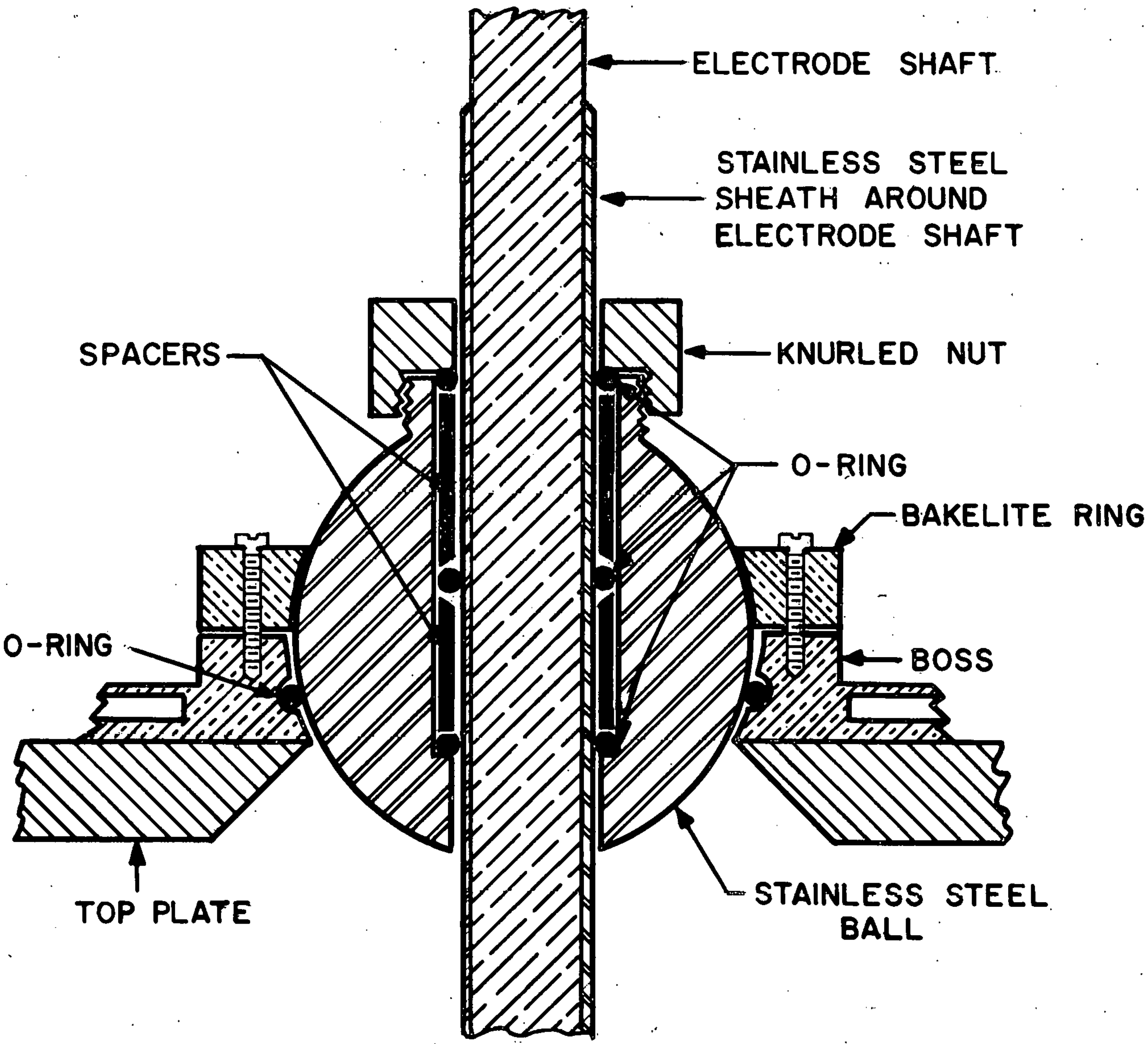

Fig. 5 - Details of the Ball and Movable Shaft Mechanism.

in the boss and is held firmly against the O-ring by a bakelite pressure ring. The top plate is cut back as shown so that the shaft can be turned to the side as far as desired.

For evacuation of the melting chamber prior to the introduction of helium or argon, both mechanical and diffusion pumps are used. The pressure in the evacuated chamber is measured by a National Research Corporation ionization gauge.

Power is supplied from a Westinghouse 800 ampere (maximum) DC welder. The positive terminal of the welder is connected to the movable electrode. A Westinghouse high frequency stabilizer is used to initiate the arc. With the stabilizer turned on, a spark discharge passes continuously between the electrode and the hearth. Power from the welder is switched off and on by a foot switch and regulated by a remote control unit operated from a switch on the panel.

OPERATION OF THE ARC FURNACE

The furnace is constructed so that several charges can be melted without opening the chamber. The first of these to be melted is a getter charge of zirconium or other suitable material for the absorption of contaminants introduced with the inert gas or released from the chamber walls by the heat of the arc. In ordinary operation, the getter charge provides sufficient purification of the inert gas.

Introduction of the inert gas usually is performed in the following manner.

After charges have been placed on the hearth plate, the furnace is closed and evacuated to a pressure of 10^{-5} mm Hg or less. The valve to the vacuum line is then closed and helium admitted to the desired pressure. In some instances, this pressure is relatively low but usually melting is done at helium pressures of 1 to 1.3 atm.

Although the arc produces considerable mixing of the molten metal, the bottom one-third to one-half of the charge usually remains solid because of the cooling action of the water-cooled hearth plate; accordingly, completely homogeneous alloys are difficult to prepare. The homogeniety is improved by remelting and inverting the alloy several times. The inverting is done by manipulating the samples with the electrode tip while the power is turned off but usually with the stabilizer still operating. The spark discharge furnishes sufficient light for the operator to see the interior of the furnace.

The crucible is cleaned after melting each set of ingots with a 1:1 solution of nitric acid and water. The acid solution is removed with water and the crucible rinsed with acetone.

GENERAL COMMENTS

Contamination of the ingot from the copper hearth or the tungsten tip ordinarily is negligible. Unless the ingot actually sticks to the hearth, no copper is likely to be introduced. Contamination with tungsten may occur if the electrode tip has actual contact with the molten alloy.

The mechanical pump should be operated continuously to prevent moisture from collecting on the interior of the melting chamber. If the apparatus has been allowed to remain open for more than a short time, several getter melts should be made in succession.

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