# A Hydrogen-Oxygen Vertical Brazing Furnace

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## ABSTRACT

A specially designed hydrogen-oxygen vertical flame furnace was constructed for brazing together the copper pieces of the accelerator structure for Stanford's Two-Mile Linear Electron Accelerator. To date, over 60,000 braze joints have been made without a leak appearing in any joint even though the brazed section operates at less than $10^{-8}$ torr pressure. The accelerator structure is a disk-loaded waveguide and is fabricated from precision-machined, high purity copper cylinders and disks, each approximately four inches in diameter. These components, with input and output coupler assemblies, are carefully stacked together with a shim of silver-copper brazing alloy placed between each piece. When stacking is complete, a ten-foot section of the accelerator structure is ready for brazing and is secured on a mandrel for transfer to the furnace. Purging gas is fed through the mandrel to the interior of the ten-foot section to prevent oxidation during brazing. Also, as the section is brazed by the split-ring burner of the furnace, a special, water-cooled cylinder filled with reducing gas follows the burner to protect the exterior of the section and prevent oxidation. The furnace provides excellent control of the brazing alloy fillet inside the disk-loaded waveguide section and prevents the alloy from increasing the rf loss on the section's inner surface.

## INTRODUCTION

The accelerator structure for the Stanford Two-Mile Linear Electron Accelerator is made of OFHC* copper cylinders and disks (Fig. 1), assembled in ten-foot sections. Several methods were evaluated for fabrication of these components to form the 10,000 feet of disk-loaded waveguide required for the structure. Among these was an electroforming process which was found to be successful but not ideal for this application. This was because the technique lacked flexibility or adaptability to associated processes and requirements, and because it was too slow. (Nine days were required to electroform a ten-foot section of the accelerator.) For these reasons, it was decided that a brazing technique would be developed for structure fabrication.

The study of various brazing techniques led to the development of a new type of furnace. The major features of this furnace are a moving ring burner which is fired by an hydrogen-oxygen flame, and a water-cooled cylinder that has a reducing atmosphere to protect the surface of the copper while it is being brazed and to cool it after brazing.

## DESCRIPTION OF FURNACE

The main components of the flame furnace (Fig. 2) are the split-ring burner, the upper water-cooled cylinder, the lower water-cooled cylinder, the ring burner lead screw set, the cylinder lead screw set, and the water baffle. The mandrel, though not a part of the furnace assembly itself, has an important part in its operation and in the transportation of the accelerator section. Also shown on the illustration is the V-block in which a section of accelerator is stacked prior to its movement to the furnace. Not shown is the operator's console which is also a part of the furnace. It moves vertically with the moving split-ring burner so that the operator can monitor and control the brazing operation.

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The split-ring burner, which is made of brass, has the flame jets where the hydrogen-oxygen mixture is ignited. The ring halves snap together around the accelerator section and are moved downward by the lead screw set at a steady rate of speed during the brazing cycle. A pre-heater is also a part of the ring burner. It has a downward flame that provides a protective hydrogen cover approximately a foot below the ring burner flame. This is to prevent oxidation in this area as the bottom edge of the ring burner flame approaches. Both the ring burner and the pre-heater are water cooled and an automatic shut-off is provided to stop burning in the event of water failure.

The upper water-cooled cylinder is approximately 18 inches in diameter and is encircled by water tubes. As the split-ring burner moves down the accelerator section, the cylinder moves down behind it. The cylinder functions to provide both controlled cooling for the brazed section and to protect its surface from oxidizing. This protection is provided by a forming gas (10% hydrogen and 90% nitrogen) flowing into the cooling cylinder. The nose cone or bottom end of the cooling cylinder is split to allow the disk-loaded waveguide to be inserted into the furnace. The nose cone limits the escape of the purging gas mixture from the bottom of the cylinder but cannot seal it off completely because it cannot touch the disk-loaded waveguide in the center of the cylinder. When a waveguide section is inserted in the furnace, the nose cone is opened to permit the pre-brazed output coupler sub-assembly of the section to be inserted into the cooling cylinder. The cone closes about the coupler sub-assembly when purging begins prior to the start of the braze.

The input coupler sub-assembly of the accelerator section, like the output sub-assembly, has been pre-brazed in a separate furnace operation. It is inserted into the lower water-cooled cylinder when a section is installed in the furnace. This cylinder is equipped with a split nose cone similar to that on the upper cylinder. This cone also closes about the output coupler sub-assembly to limit the escape of forming gas when purging begins.

The two sets of lead screws are necessary because the split-ring burner and the water-cooled cylinder move down the furnace at different rates of speed, particularly at the beginning and end of the brazing cycle. These rates are set by two separate speed controllers on the operator's console.

The mandrel to which each section of the disk-loaded waveguide is clamped, and by which it is transported, is a hollow tube that passes through the hole in the disks of the waveguide. It is connected in the furnace to a vertical hollow tube that feeds a hydrogen-nitrogen reducing gas mixture into it. The gas passes through holes in the mandrel and into the ten-foot section during brazing.

## FURNACE OPERATION

Before a ten-foot section of accelerator is mounted in the flame furnace, the split-ring burner and the upper water-cooled cylinder are moved to the top of the furnace assembly. A mixture of 10% hydrogen and 90% nitrogen gas is fed through the vertical support pipe of the furnace and into the mandrel for a purging period of 15 minutes after the section is secured in the furnace

(Fig. 3). At the same time, the upper and lower water-cooled cylinders are also purged for 15 minutes.

Following the purging, the hydrogen-oxygen reducing flame is ignited. The flame is hydrogen rich, again to prevent oxidation, and the flow rates are 1,000 cu ft/hr for the hydrogen and 80 cu ft/hr for the oxygen. The pressures under which the flame is fed are 42 psi for hydrogen and 45 psi for oxygen. When the melting point of the brazing alloy is reached (approximately 783°C), the operator starts the simultaneous movement of the split-ring burner and the upper water-cooled cylinder. Figure 4 is a photo showing the moving flame and a part of a section being brazed.

The split-ring burner moves down the cylinder at a set rate. The operator compensates for any changes in the heat from the flame by varying the speed of the water-cooled cylinder. As he observes the speed of melting of the alloy, he can raise the intensity of the heat and the melting speed by widening the distance between the bottom of the cylinder and the burner. To slow the rate of melting and effectively decrease the intensity of the flame, he narrows this distance. There are 146 alloy washers for each ten-foot section being brazed and the operator is able to observe each of them as they melt.

The brazing cycle takes approximately 25 minutes for the 220-pound section of waveguide. The section then requires approximately two hours to cool prior to its removal from the furnace.

Low conductivity water is piped at six gpm to all components of the furnace that are in close proximity to the flame or to the brazed accelerator section. A sensing device is located in the water line to the split-ring burner and the pre-heater. When water flow is cut off at this point, an interlock is tripped and a solenoid operated, immediately stopping the brazing cycle and preventing the two burners from melting.


## ACKNOWLEDGMENTS

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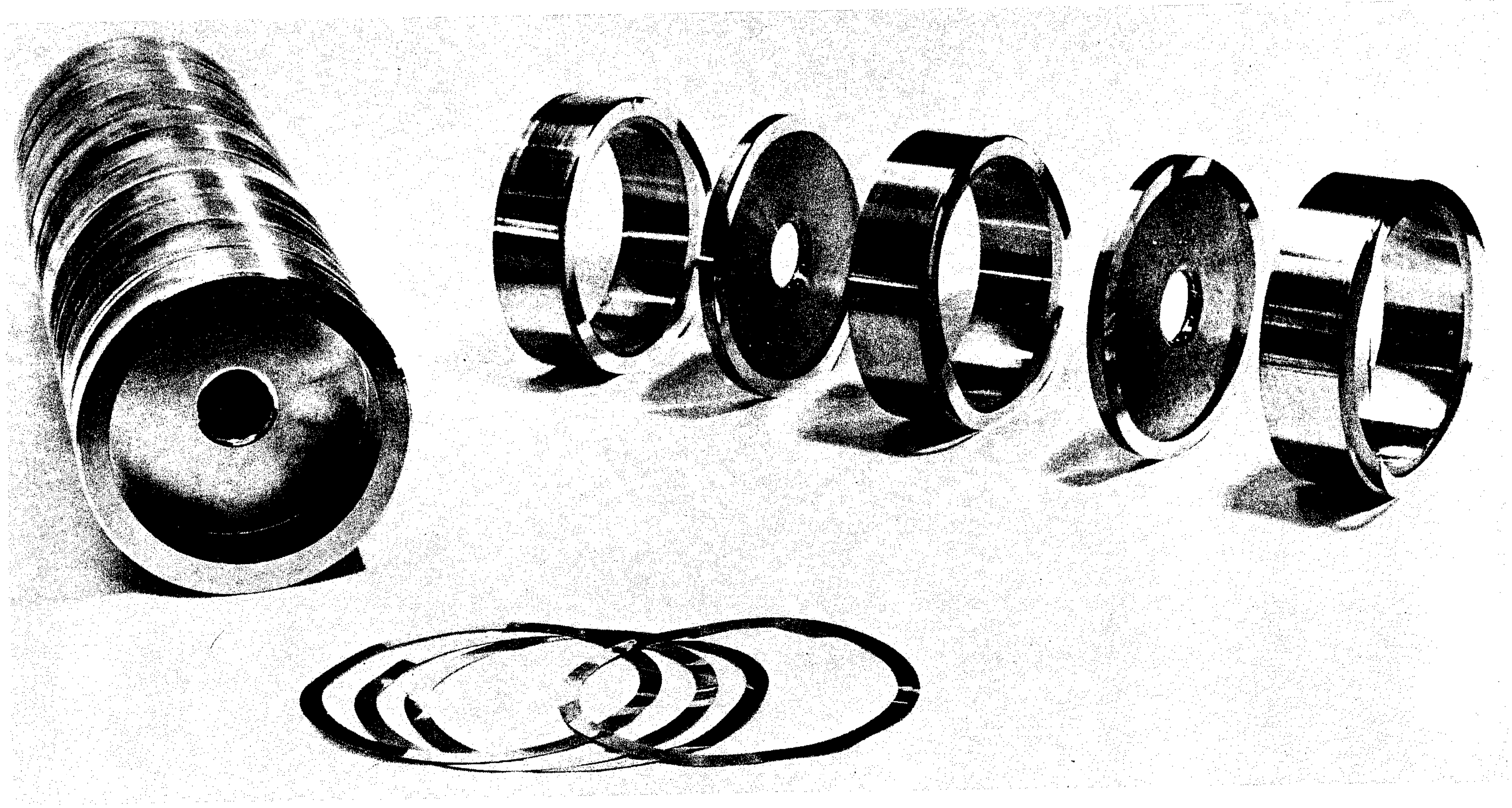

FIG. 1--Cylinders, disks, and brazing washers of accelerator section.

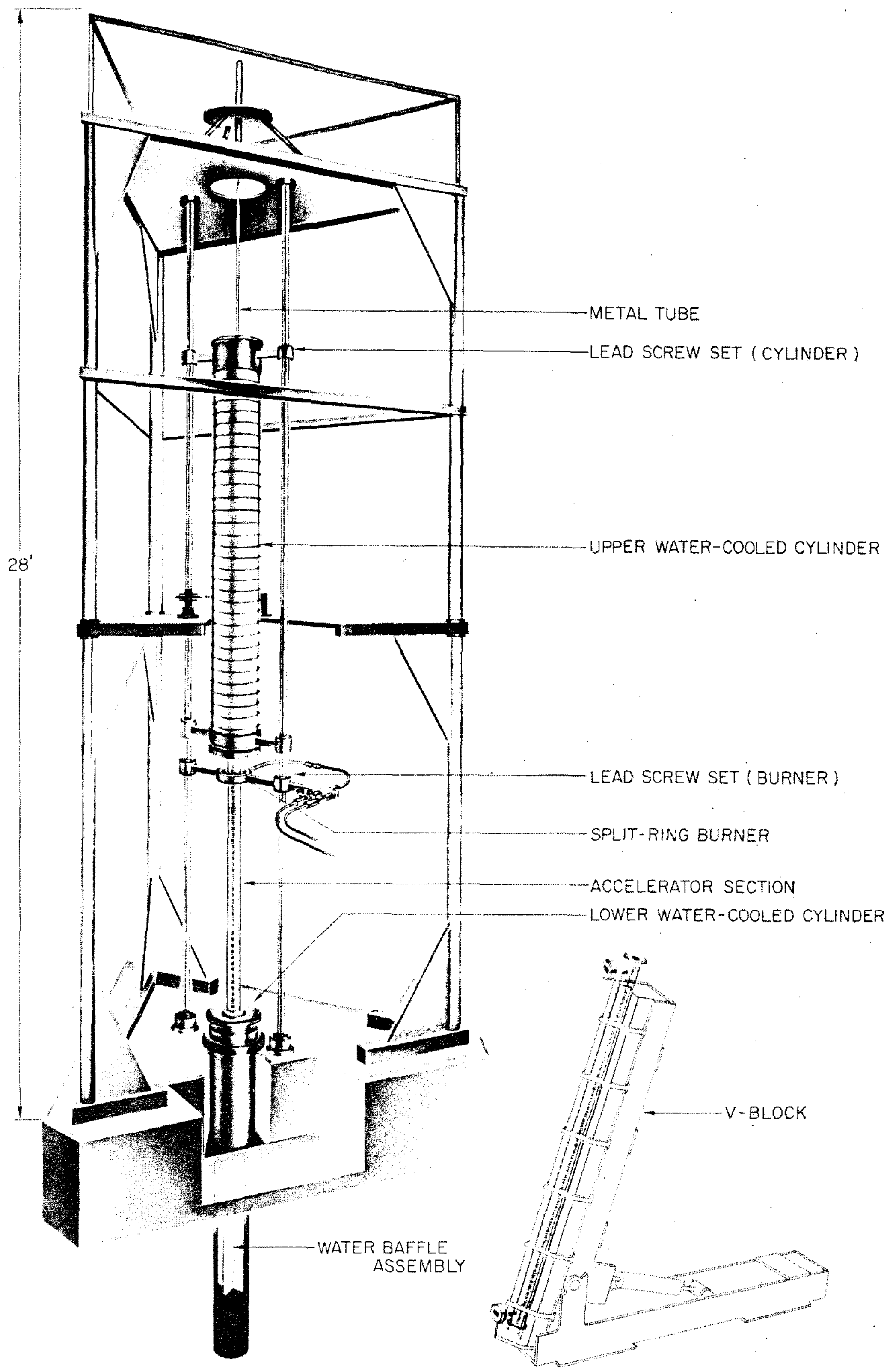


FIG.2 SCHEMATIC VIEW OF FLAME FURNACE

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FIG. 3--Accelerator section at start of braze.

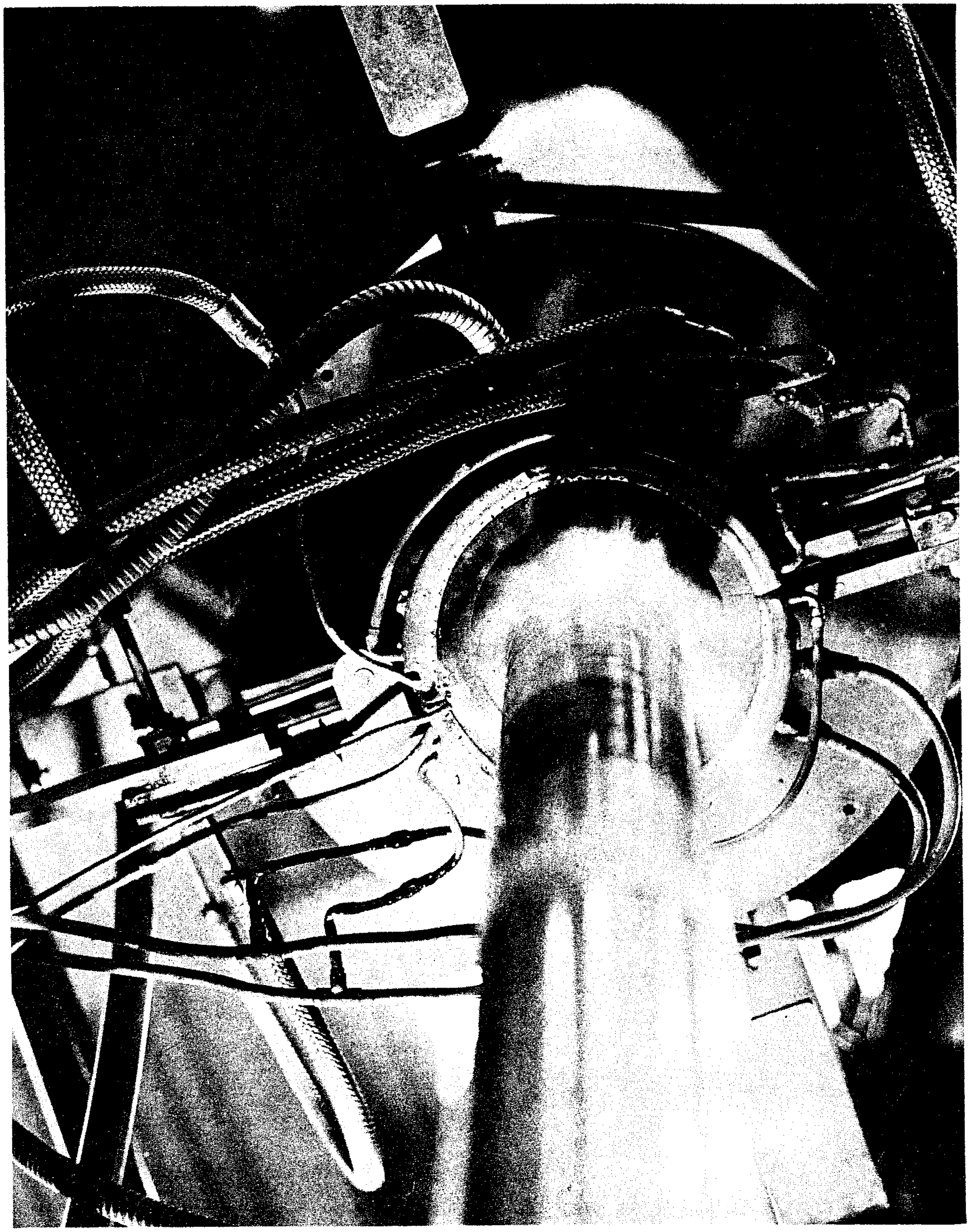

FIG. 4--Split-ring burner in operation