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SILVER BRAZING METHODS FOR JOINING THE OH AND SF FIELD COIL TURNS FOR THE PLT MACHINE

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Summary

This paper describes the techniques, materials, and equipment used to silver-braze the OH and SF field coils in-place in the PLT machine.

Introduction

The PLT is a large Tokamak device now undergoing final power test at Princeton. The PLT design approach utilizes and extends the technology developed for the ATC device, completed in 1972.

The TF coils are conventionally wound double pancake, epoxy-cast coils. The poloidal coils are located in the bore of the TF coils, and as a consequence, were fabricated in place. The in-place fabrication necessitated numerous silver-brazed joints. A typical brazing set-up is shown in Fig. 1. Fig. 2 shows the arrangement of the poloidal coils in relation to the TF coils and the vacuum chamber. Unlike the ATC, which utilized flexible watercooled cable and straps in the poloidal coils, the PLT windings are made of rigid extruded copper conductors.

The SF and OH systems together consist of 348 turns. The conductor sizes range from 1/2" x 1/2" to 7/8" x 1-1/4". All have a centrally located 1/4" diameter hole for water cooling.

In-place Fabrication Methods

The design details of the SF and OH coil systems were described in a previous paper.[1] Basically, insulated conductors are wound into coils; each of the turns are cut into two or three segments to permit insertion into the bore of the TF coils through the gaps between them. The segment ends are scarfed on a 30° angle and counter-bored for a copper sleeve for continuation of the water passage when the segments are silver-brazed together in the machine. After all the segments of a coil group are prepared as outlined above, they are fitted together at a mock-up area and codified for easy identification prior to delivery at the PLT assembly site.

Each of the segments are sequentially "snaked" into the bore of the TF coils, silver-brazed with induction heating, cleaned up, pressure tested, and insulated where the insulation was removed (approximately 12" on either side of the joint). As coil groups were completed, water flow and electrical tests were performed.

In total, 1200 brazes were required to fabricate the poloidal coils in-place. A water leak in any joint would have serious consequences. The success of the brazing methods was therefore of considerable importance to the success of the in-place poloidal coil fabrication. Considerable effort was expended on this task to assure that reliable, repeatable brazes could be made on an efficient basis.

The in-place fabrication phase of the PLT was completed over a period of nine months; during much of this period, crews worked around the clock. Only two brazes had to be re-made because of the malfunctions of the automatic infra-red temperature controller incorporated into our brazing system.

Development Tests

The copper cleaning techniques, brazing alloy, work coil, fixture design, and induction equipment were chosen after analyzing several hundred sample joints. The samples were tensile tested, pressure tested, and sectioned. Typical test specimens are shown in Figs. 3 and 4. Non-destructive testing techniques, namely ultrasonic testing and X-ray photography were attempted, but without much success because of the nature of the scarf joint. Brazes were also made under non-optimum conditions to determine the critical factors in successful brazing. Proper copper cleaning, joint alignment and fixturing, and correct control of the time-temperature cycle were found to have the most significant effects. Initial plans called for pull-testing each brazed joint; however, preliminary tests of samples brazed, using the methods chosen, and pull-testing of the first joints in the machine increased confidence to the point of omitting such further testing.

Brazing by induction heating was chosen over other methods for several reasons. This method was used very successfully to braze the copper conductors in the PLT TF coil, and can be performed in confined areas because of the small size of the work coil (heating coil). The heating cycle can be closely controlled.

Description of the Induction Brazing and Control System

The induction brazing system used on PLT consists of a static high-frequency (10 kHz) power supply with a rating of 50 kW and a mobile heat station containing a transformer and capacitors to tune the circuit. This system is illustrated in Figs. 5 and 6. The system was supplied by the Taylor-Winfield Corporation. The static type of supply was selected in preference to the more common motor-generator type for the following reasons. The primary advantage of the static supply is its variable output frequency. This both controls the power level through the frequency characteristics of the circuit and permits tuning over a wider range of bar sizes without changing the transformer ratio or amount of capacitance. By varying the frequency of the power supply output, more or less power is available at the work coil. Other advantages of the static-type supply is smaller size and less weight, silent operation when idling, and ease of operation since the unit is electronically protected against most malfunctions. The physical considerations were important because of the location of the supply on the PLT platform.

The infra-red temperature controller was supplied by the Ircon Corporation. Interfacing with the power supply was accomplished by adding a small circuit board and making a few connections. The infra-red sensor is aimed at the joint being brazed; the temperature of the bar is indicated by a meter on the remotely located control unit. An output signal from the control unit is fed to the temperature control circuit board, which in turn varies the output frequency. Very little temperature overshoot is experienced, since it gradually decreases power as the temperature increases.

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The Induction Heating Coil

The basic requirements of the work coil were that it be capable of uniformly heating all of the copper bar sizes used in the PLT poloidal coils in 150 seconds or less and be compact enough to fit in the limited fabrication space available. Many variations of work coils were investigated. The final work coil, shown in Fig. 7, is a compromise of the designs studied. It met all of the design requirements and has given excellent results. The coil was made of 0.287" square ETP copper with a round 0.161" I.D. hole. The flow rate through the work coil is 0.75 gpm with a pressure drop of 30 psi and results in a temperature rise of 100°F during maximum power conditions. It is capable of brazing copper bars from 1/2" square to 7/8" x 1-1/4" without any manual retuning of the power supply.

Joint Details

The parts necessary and the joint make-up are shown in Fig. 8. The joints are scarfed on 30° angles. The copper sleeves are 0.002" to 0.004" undersized to the diameter of the counterbore. The pre-formed rings of silver are used to seal the ends of the sleeve. Silver wafers and hairpins are used to seal the joints.

'Sil-Fos' was chosen as the braze filler metal because it produces a strong joint without the use of fluxes, which could become entrapped. The 5%P in Sil-Fos is adequate as a wetting agent.

Joint Cleaning

The joint surfaces and components are polished with 'Scotchbrite' pads and cleaned with a 1:4 solution of 'Enthone Enplate' #AD-482 and water. A properly cleaned joint will exhibit a uniformly wetted surface. The cleaned surfaces are protected from contamination until used; handling is done with gloves or tweezers.

Joint Fixturing

The support table of the brazing fixture and alignment jigs are shown in Figs. 9 and 10. After the bar is properly aligned and clamped, the clamp arm containing the work coil is placed over joint and the pivot pin is inserted. A lava block is placed between the clamp arm and joint, and the clamp is tightened. This keeps the joint halves from over-riding, allows for expansion to close the joint. Excess expansion slips under the clamps.

Joint Brazing

The 'Ircon' infra-red detector with a stainless steel mirror at 45° is attached to the support table. The induction work coil is energized and the brazing cycle is automatically controlled. The bar is heated to the preset temperature limit of 1250°F, soaked for 2-6 seconds, and shut off. At the conclusion of the braze, the clamp with work coil is removed, and the work is allowed to cool. The work is unclamped, the joint inspected, filed, cleaned, pressure-tested and reinspected.

Acknowledgments

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References

[1] H. C. Johnson, "Design Aspects of OH and SF Coils for the PLT Machine," Proceedings of the Fifth Symposium on Engineering Problems of Fusion Research, IEEE Pub. No. 73CH0843-3NPS (1973).

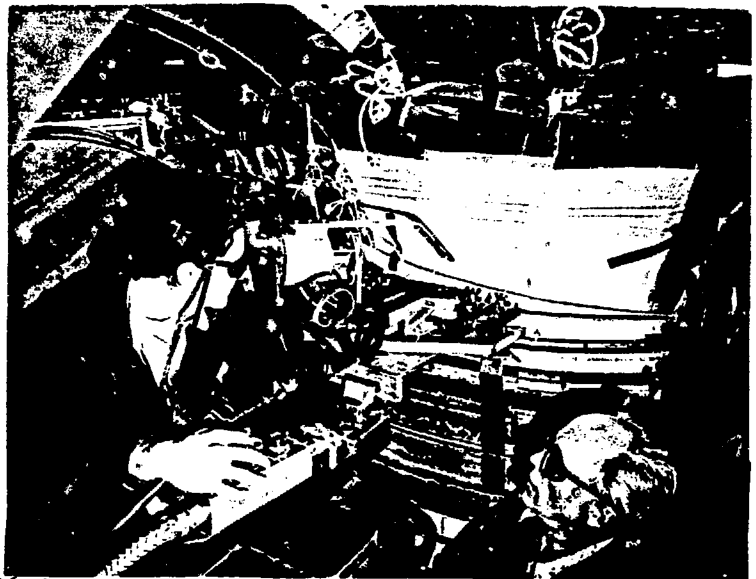

FIG. 1

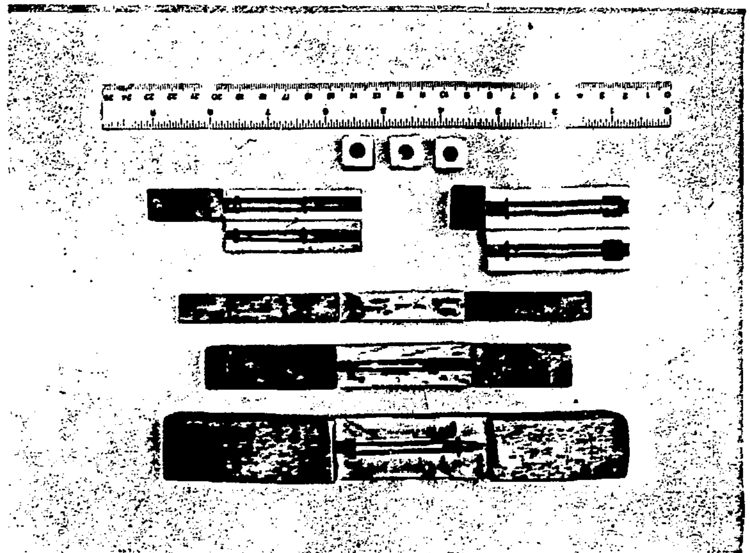

FIG. 3

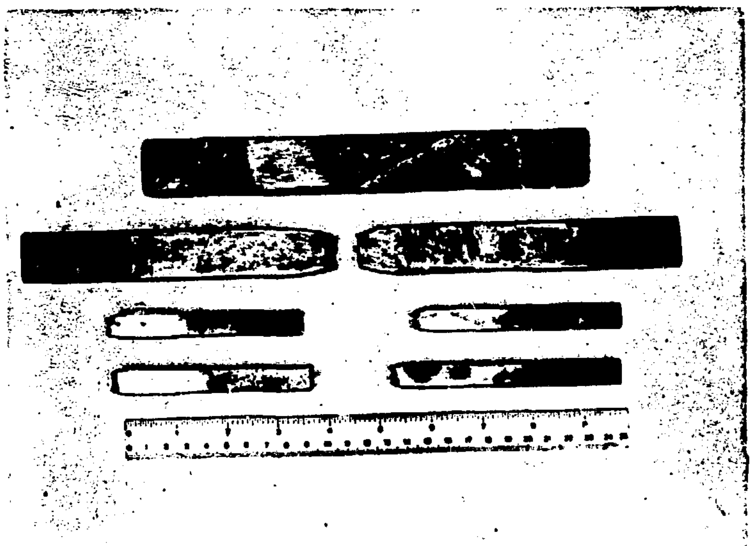

FIG. 4

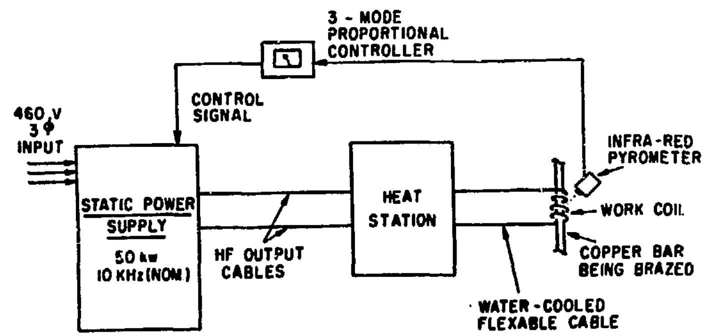

FIG. 5

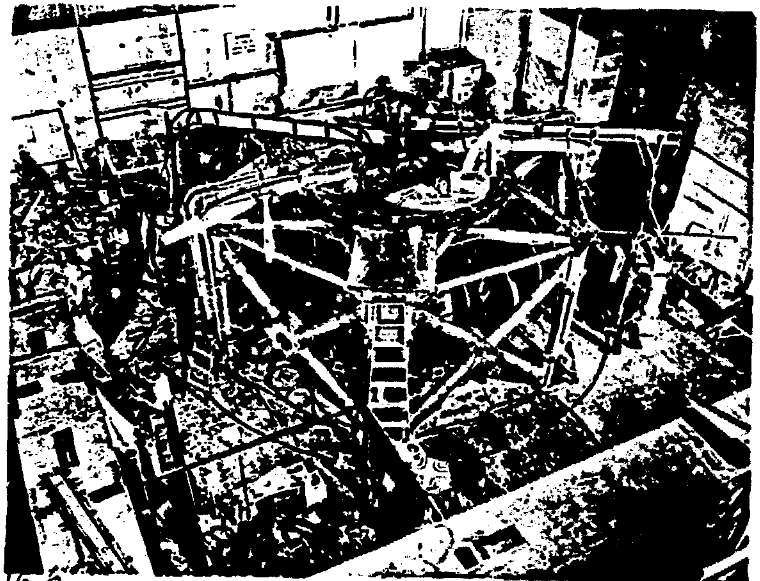

Fig. 6

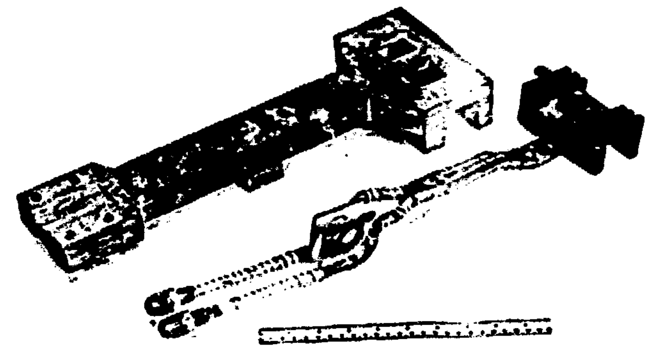

Fig. 8

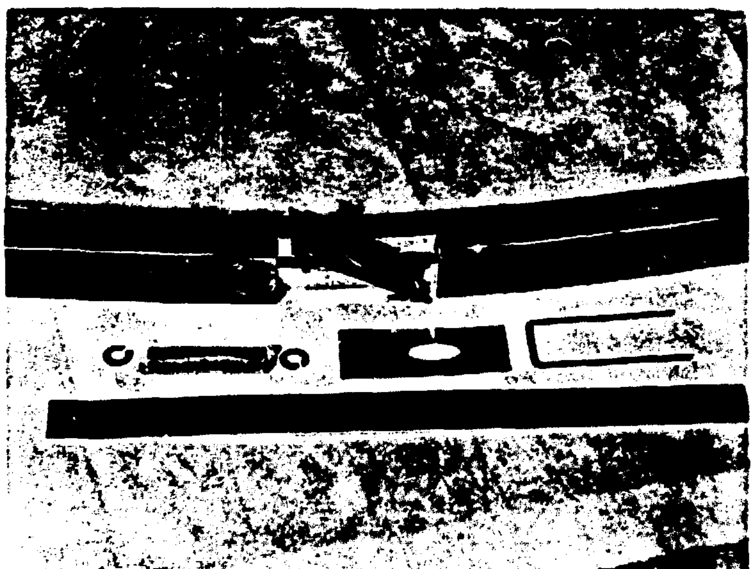

Fig. 5

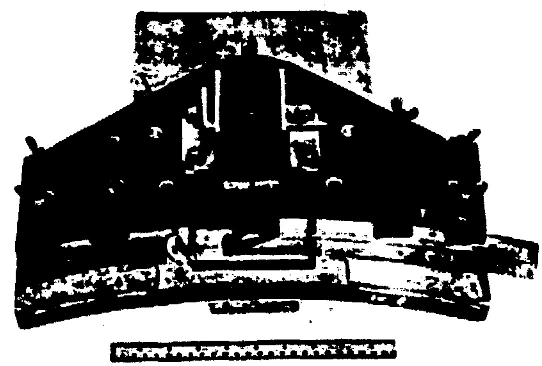

Fig. 7

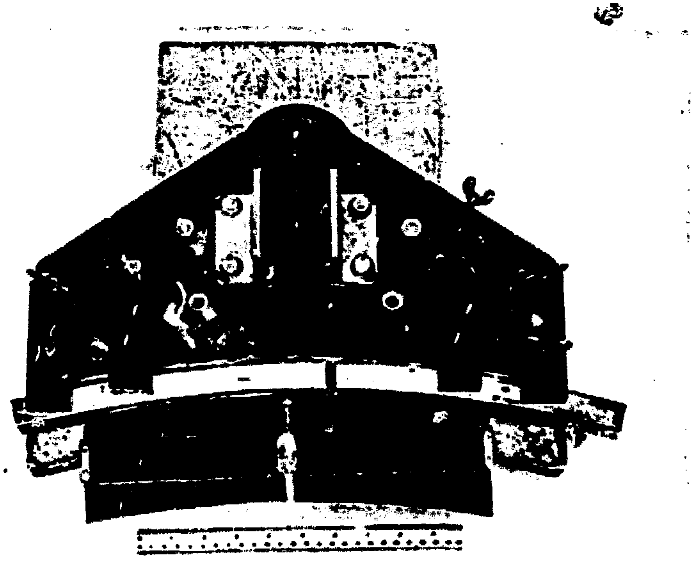

FIG. 10