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**Accelerator Drift-Tube Braze-Joint Failures
In the PIGMI APF Cavity**

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ACCELERATOR DRIFT-TUBE BRAZE-JOINT FAILURES IN THE PIGMI APF CAVITY

by

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ABSTRACT

During the assembly of the Alternating Phase Focusing cavity for the PIGMI Prototype proton accelerator, recurring failures of drift-tube braze joints occurred. In the fabrication technique, a torch braze was used to attach the stems to both the drift-tube body and the stem termination; all materials used were stainless steel. The assemblies were copper plated, using bright-acid-leveling copper plating. Some braze joints, although satisfactorily tension-tested before plating, later failed at a relatively low loading. A detailed investigation of one drift tube indicated that residual copper-plating solution in the cooling passages acted to dissolve the braze solution over a period of weeks, leading to an eventual joint failure.

I. INTRODUCTION

The PIGMI (Pion Generator for Medical Irradiation) Prototype accelerator^{1,2} was constructed at the Los Alamos Scientific Laboratory (LASL) to test a new type of low-energy proton accelerating structure called the Alternating Phase Focusing (APF) structure. The APF cavity is shown in Fig. 1. It is 63.3 cm long, has a 46.0-cm i.d., and contains 28 drift tubes. Odd-numbered drift tubes are rotated 60° about the axis, because drift-tube spacing otherwise is too close to allow installation of the stem terminations. Each drift tube has three stems that act as cooling-water passages, as shown in Fig. 2. All stems are held under tension by a spring in the termination of the water outlet stem, and radial position is adjusted by threaded positioners in the other two (water inlet) stems. Axial alignment of the

Fig. 1.
APF cavity with three-stem drift tubes.

drift tubes is accomplished by physically bending the drift-tube stems after the drift tube has been installed in the APF tank.

The APF drift tubes were loaded into the APF tank by the following procedure. The drift tube (Fig. 3) was loaded into a holder, and tubes were slipped over the stems to protect the copper plating (Fig. 4). The drift-tube stems were then inserted through the stem termination holes in the APF tank (Figs. 5, 6, and 7). Insertion of the last stem required the stems to be bent ~ 1.9 cm over its 19.0-cm length. Once the drift tube was in place, the stem-termination hardware was installed, the stems were tensioned, and the drift tube was aligned.

The drift-tube body material was type 304 stainless steel, and the stem material was 0.30-cm-diam, 0.03-cm-wall, type 304 stainless steel hypodermic tubing. The stems were torch brazed into the drift-tube body, using Easy-Flo 45 Braze with Handy-Flux Type B-1 Flux.

Fig. 2.
PIGMI three-stem drift tubes and typical stem termination.

Fig. 3.
Drift-tube body, stems, and stem termination before brazing.

Fig. 4.
Drift-tube prepared for insertion into APF tank.

Fig. 5.
Drift-tube installation into
APF tank: first stem.

Fig. 6.
Drift-tube installation into
APF tank: second stem.

Fig. 7.
Drift-tube installation into APF tank:
third stem.

A fixture was used to properly position the stems, and cooling jackets were fitted to the stem so that the hypodermic tubing was annealed only in the region less than 1 cm from the joint itself; this allowed most of the stem to remain "springy", a necessary condition for drift-tube insertion into the tank. All brazing was done by experienced, knowledgeable personnel; externally the braze joints showed proper flow of material and surface indications of correct temperature. The completed drift-tube assembly was then vacuum-leak checked; each stem was checked for strength with a static tension load of 61 kg, which was more than twice the maximum load attainable with the stem-termination hardware.

Following mechanical fabrication, the drift tube was plated with a minimum of 0.01 cm of copper, using the bright-acid-leveling copper-plating technique. The copper-plating solutions to which the drift tubes are exposed are, in sequential order,

- (1) caustic cleaner (sodium hydroxide) for ~ 30 s,
- (2) summa polish (acid) for ~ 1 min,
- (3) 70 vol % sulfuric acid for ~ 30 s,
- (4) nickel strike solution (acid) for ~ 1 min,
- (5) copper strike (cyanide) for ~ 1 min,
- (6) 10 vol % sulfuric acid for ~ 1 min,
- (7) bright-acid copper-plating solution (~ 1 h/0.003-cm plate thickness), and
- (8) chromate solution for ~ 5 s.

During plating operations, the cooling passages were not sealed off from the plating solutions. The cooling passages were cleaned by a water rinse immediately following plating, and the drift tube was then ready for installation in the APF tank.

During the first installation of the drift tubes in the APF tank, eight stem-to-drift-tube braze joints failed. After a braze-joint failure, the copper plate had to be stripped from the drift tube and all stems had to be replaced. The copper-plating sequence was then repeated. For physics reasons, it was necessary to remove and reinstall the 28 APF drift tubes three times. Seven additional braze-joint failures occurred during these operations. When the cavity frequency was properly adjusted (by the addition of more plating to the drift tubes), the tank was placed under vacuum. Five drift tubes had vacuum leaks; these leaks were stopped by a liberal application of an organic sealing material (Vac Seal) inside the cooling passages. These leaks recurred periodically during testing. The first drift tube was installed in the APF tank on January 22, 1979, and 15 braze joints (out of 168) failed before the APF was successfully tested on August 7, 1979.

II. PRELIMINARY ANALYSIS

The failure of the APF drift-tube braze joints was a vexing problem. Before plating, all joints were subjected to a 61-kg static-tension test. One stem, before plating, was subjected to a 137-kg static-tensile load, with no joint breakage or deformation. When installed in the APF tank, the maximum tension on the stems was less than 25 kg. The first braze-joint failures initially were attributed to inadequate penetration of the braze material between the stem and the drift tube body. Brazing tests were made with several brazing compounds. These were

<u>Braze</u>	<u>Flow Point</u>	<u>Composition</u>
Easy-Flo 45	1145°F	45% Ag, 15% Cu, 16% Zn, 24% Cd
Braze 560	1205°F	56% Ag, 22% Cu, 17% Zn, 5% Sn
Braze 603	1325°F	60% Ag, 30% Cu, 10% Sn
Braze 702 (BT)	1435°F	72% Ag, 28% Cu

The Easy-Flo 45 test braze was done as follows: apply flux to the stem, heat the drift-tube body to a dull red, insert the stem, and heat until the ring of braze material flows on the stem and "blushes" on the body. The braze did not fully penetrate; however, the test stem did pass the 61-kg tension test satisfactorily. Test brazes using Brazes 560, 603, and BT also were done; in these cases, the braze did penetrate, with Braze 603 showing the best penetration. The 10% Sn in Braze 603 appreciably seems to aid in "wetting" the stainless steel, which increases the penetration of the liquid braze material. The results of these tests were inconclusive, however, because it was felt that any of these brazes should result in a reliable joint of adequate strength, particularly if a nickel strike (which also improves the "wetting" ability of the brazes on stainless steel) were applied to the stems before the brazing operation.

As the braze joints continued to fail, it became increasingly apparent that a mechanism besides that of a possibly substandard joint, initially caused by poor braze penetration, must be operating. On several failed joints, it was noted that little braze material remained, and surrounding the edge of the braze was a ring of blackish material. Finally, while preparing to insert drift tube #2, a stem-to-body braze joint failed while experiencing no axial-tension force, no rotational force, and a slight movement being applied by hand to straighten a minor bend in the stem. Examination of this failed joint revealed that the braze-joint fillet appeared to have been completely eaten away from the inside, and only the copper plating was holding the stem to the body. Eight unplated drift tubes, which were fabricated for another tank, were tension-tested (with a 61-kg static load) about eight months after the brazing operations had been completed. This tension test revealed no failures in this group of unplated drift tubes, and a vacuum-leak check of the drift tubes was also satisfactory. Because the cooling passages had not been plugged to keep out the various plating fluids, and because the failures were all occurring after the copper plating had been done, it was then hypothesized that some sort of chemical corrosion was occurring, involving plating fluids trapped in the drift-tube cooling passages. After the tests of the APF cavity, drift tube #13 (which had been the worst drift tube from the standpoint of reoccurring vacuum leaks during operation) was removed and sent to CMB-8 for microscopic analysis.

III. MICROSCOPIC ANALYSIS

The cause of the drift-tube braze-joint failures was determined by performing metallographic examinations of three stem-to-termination joints of APF Drift Tube #13. The three joints had the following histories:

- Joint 1. As-brazed; no subsequent cleaning or plating.
- Joint 2. Removed for sectioning immediately following bright-acid copper plating. No attempt made to prevent access of plating solutions to interior of assembly.
- Joint 3. Same as Joint 2, but held without additional cleaning for 45 days before sectioning.

Longitudinal metallographic sections through the three joints are shown in Figs. 8, 9, and 10. (The small spheres in the interiors of the joints are pelletized alumina, added as an aid in sample preparation.) Figures 11-16 show, in more detail, the extent of filling of the space between the tubing and the fitting of each joint with the brazing alloy. It is not apparent at these magnifications, but there is lack of contact, over appreciable distances, between the braze and the adjacent stainless steel fitting. This gap is often of only a few micrometers, and sometimes is visible only at magnifications of 500X or more. The extent of this gap is indicated with dashed-line overlays in Figs. 8-10. Comparing the three figures, it is apparent that there is a considerable difference between the effective contact area (and, therefore, mechanical strength) in Fig. 8 and the contact areas of Figs. 9 and 10. Either the contact area was greater in Joint 1 than in the others, following brazing, or something has diminished the contact areas in Joints 1 and 2 since the brazing took place.

In Figs. 17-20, arrows indicate where metallic copper was found by visual examination and confirmed by electron microprobe analyses. No such particles of elemental copper were found in Joint 1, which was not attached to the assembly when it was immersed in the copper-plating solution. In addition, porous areas are visible in the braze alloy in Figs. 7-20, which were not visible in Joint 1.

The explanation of the joint failures evidently is the following. No effort was made to exclude the plating solution from the interior of the assembly during electroplating of the copper onto the exterior. Following the

electroplating, the perfunctory flushing of the interior was insufficient to remove all traces of the copper-bearing electroplating solution from crevices in the brazed joints. Over a period of several weeks or months, the remaining electroplating solution reacted with the brazing alloy (Easy-Flo 45), removing zinc and/or cadmium into solution and precipitating copper elsewhere. (This is a variation on the production of so-called "cementation copper", in which the iron in tin cans or scrap iron, when immersed in copper-bearing mine effluent, precipitates the more valuable copper from solution.) In the process, braze alloy is removed along the interface between it and the stainless steel. Figure 21, a higher-magnification view of the area in Fig. 19, shows the typical appearance of the resulting gap, together with arrows indicating where precipitated copper was observed. In this view, 1 mm on the photomicrograph is the equivalent of 2 μm on the specimen; therefore, the width of the gap varies from about 2 μm to less than 1 μm along this length.

IV. CONCLUSIONS

The failures of the APF drift-tube torch-braze joints basically can be attributed to chemical corrosion of the braze material by trapped electroplating solution inside the joint. To prevent future occurrences of this type, the following conclusions are reached:

- (1) Improve the braze penetration by applying a nickel strike to stainless steel parts before brazing.
- (2) If a nickel strike cannot be used, use either braze 560 or 603, whose tin content will better wet the stainless steel surfaces and improve penetration.
- (3) Use a surface pyrometer or candle to ensure that the pieces reach the required temperature for good braze flow.
- (4) Apply flux to both pieces being brazed.
- (5) Ensure that the electroplating solutions do not contact the braze joint (except in the external area of the braze fillet) to prevent internal corrosion, and removal of the braze material.

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Fig. 8.
Joint 1. 10X.

Fig. 9.
Joint 2. 10X.

Fig. 10.
Joint 3. 10X.

Fig. 11.
Left half of Joint 1. 20X.

Fig. 12.
Right half of Joint 1. 20X.

Fig. 13.
Left half of Joint 2. 20X.

Fig. 14.
Right half of Joint 2. 20X.

Fig. 15.
Left half of Joint 3. 20X.

Fig. 16.
Right half of Joint 3. 20X.

Fig. 17.
Left side of Joint 2. 200X.

Fig. 18.
Right side of Joint 2. 200X.

Fig. 19.
Left side of Joint 3. 200X.

Fig. 20.
Right side of Joint 3. 200X.

Fig. 21.
Left side of Joint 3. 500X.