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Section T-IV

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THE SITE B FOUNDRY

(Final Report on Part I of P.A. No. 151-ML-54-2, F.S. 41)

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THE SITE B FOUNDRY

Summary

The Site B Foundry is equipped for the melting and casting of tuballoy and its alloys. Castings weighing up to 750 pounds and as long as 40 inches can be made. Melting can be carried out in vacuum, in inert gases or under fluxes. Heating is by high frequency induction.

A description of the general foundry layout, the furnace construction and operation, and of the auxiliary equipment is given in this report.

The casting technique used in the Site B Foundry is designed to minimize piping and cold shuts in the billets. The top of the mold is kept hot and freezing of the billet takes place from the bottom. This hot topping minimizes piping. Controlled pouring into warm molds minimized cold shuts.

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I. Purpose and Capacity of the Site B Foundry

The Site B Foundry has been set up for the purpose of casting special shapes of tuballoy as are required by Project Members, for the carrying on of melting and casting research, and for the preparation of alloys of tuballoy. With the present equipment, castings from a few pounds up to 700 pounds and as long as forty inches can be made. Although the foundry furnaces are designed primarily for melting and casting in vacuum, melts under fluxes and in inert gases can be made.

II. General Layout of the Site B Foundry

The general layout of the Site B Foundry is shown in drawings, Figures 3 and 4, and photographs, Figures 5, 6, 7, and 8.

The melting furnaces in the Site B foundry are located on a platform so that they can be loaded and unloaded from below. A boom type crane is mounted on the wall behind the furnaces and is designed to serve both the furnace platform and the floor below. One of the 100 lb. furnaces is equipped with a hood to remove undesirable fumes formed during flux melting.

The generator room is located at the south end of the furnace platform, (see drawings figures 3 and 4, and photograph figure 8). This room contains the high frequency motor generator set, the capacitor bank, and the vacuum pump. All switches and starting boxes for operating this equipment are also located in this room. The control panel which controls the power supply to the furnaces is located on the furnace platform for more convenient operation of the furnaces (see drawings figures 3 and 4, and photographs figures 5 and 6). A forced draft air supply has been installed in the generator room to prevent foundry dust and vapors from entering the room.

High frequency power is brought to the furnaces through 4" x 1/8" bus bars enclosed in a bus box running along the front edge of the platform. Water, drain, and vacuum connections to the furnace are brought in under the platform. Valves in the water and vacuum lines can be operated either from the platform or from the floor.

III. Quartz Tube Furnace - Figure 1

This furnace has a nominal capacity of 100 pounds of tuballoy and consists, basically, of a vacuum chamber formed by a 12" quartz tube closed off at either end by steel plates. An induction coil 14 inches inside diameter and 14" long is placed around the quartz tube. A conductor placed within the vacuum chamber and the coil will be heated if a high-frequency alternating current is passed through the coil. Vacuum tight seals between the ends of the quartz tube and the steel plates are formed by rubber gaskets which are cemented into grooves in the steel plates. Actually, the top and bottom plates are made up of two or more parts which can be easily taken apart in order to make the operation of the furnace more practicable. As can be seen in the drawing, the bottom plate consists of a cylindrical steel water jacket upon which the quartz tube rests, and a flat steel plate which can be removed to lower the contents out of the furnace. The furnace top plate assembly consists of a large main top plate and an auxiliary top plate, the latter carrying the sight window and the Wilson seal through which the stopper rod extension rod slides. Since heating is accomplished by means of high frequency induction, all of the larger metal parts of the furnace must be water cooled. The inside of the quartz tube is lined

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with insulating refractories from the bottom almost to the top. At the bottom, one course of B & W K-30 bricks is placed as a foundation for a molded cylinder of sillimanite or zircon which forms the rest of the refractory lining.

The graphite crucibles used in this furnace are 8" outside diameter and 14" tall. Graphite molds of required size and shape are used. The maximum mold length which can be used in the furnace as shown in the sketch is 18 inches. Steel extensions have been built to increase this length limit. These extensions are flanged steel cylinders, closed at one end, which bolt onto the bottom of the furnace in place of the bottom plate.

The operation of the one-hundred pound quartz tube furnace may best be described by listing the steps necessary to make a casting in their chronological order. Assuming that the cycle begins with the furnace empty and the top and bottom plates removed, the steps in the furnace operation are as follows:

1. The mold is placed on the furnace bottom plate.
2. The crucible is placed above the mold, and the entire assembly is elevated into the furnace.
3. The bottom plate is bolted to the bottom of the furnace.
4. The charge is top loaded into the crucible around the stopper rod.
5. The crucible cover and top insulating bricks are put in place.
6. The furnace top plates are put into position, the end of the steel stopper rod extension being pushed through the Wilson seal in the auxiliary top plate.
7. A lead weight is placed on the stopper rod extension to prevent the stopper rod from floating out of its seat in the crucible when the charge becomes molten.
8. The furnace is evacuated, and an inert atmosphere is admitted if desired.
9. The charge is melted and brought to the proper casting temperature (1350°-1400°C for pure tuballoy). The temperature is read through the glass window in the auxiliary top plate with an optical pyrometer.
10. The molten charge is allowed to run into the mold by removing the stopper rod weight and pulling up on the rod.
11. After the crucible has cooled to a black or dull red temperature, air is admitted to the furnace, and the top plates are removed.
12. The stopper rod, top bricks and cover are removed from the crucible.
13. The bottom plate is unbolted and the plate, mold, and crucible are lowered out of the furnace.

The furnace is now ready for reassembling for making another casting.

IV. Micarta Tube Furnace - Figure 2

This furnace has a nominal capacity of three hundred pounds of tuballoy and in general, the construction is similar to that of the quartz tube furnace. The chief difference between the two furnaces lies in the fact that the three hundred pound furnace employs a micarta tube, 25 inches in diameter, in place of the quartz tube used in the smaller furnace. Since micarta may not be allowed to get hot, the entire furnace, coil included, must be placed within the tube, the tube being sufficiently large in diameter so that it does not become heated by stray heat radiation during the melting process. Since, in this case, the coil is within the vacuum chamber, it is necessary that the water and power leads to the coil be passed through the tube by means of specially designed vacuum tight fittings.

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The operation of this furnace is identical with that of the twelve inch quartz tube furnace described previously.

V. High Frequency Generator and Power Distribution System

The current used for heating the vacuum induction furnaces in the Site B Foundry is 3000 cycle, 400 volt A.C. and is supplied by a 50 KW. air cooled Westinghouse Motor-Generator Set. The capacity for the high frequency circuit is supplied by a bank of five multi-tap water cooled capacitors. In operating a furnace, the correct amount of capacity is placed in the circuit to give a power factor as near to unity as possible.

The high frequency current is carried to the furnaces by a bus-bar system. Each furnace is equipped with knife switches so that it can be easily connected to or disconnected from the main bus line.

The control panel for the high frequency circuit is located near the furnaces (see Figure 5). By means of these controls, any power from a few kilowatts to the maximum output of the generator can be obtained quickly and easily. The generator and capacitor bank are fully protected by overload relays.

VI - Vacuum System

The Site B Foundry is equipped with a manifold type vacuum system. The main vacuum line and the vacuum lines to each of the furnaces are made of extra heavy two-inch steel pipe. All threaded joints are packed with a litharge and glycerin mixture. Each furnace is equipped with its own valve and dial type vacuum gauge. A main line valve is located at the pump, and a McLeod Gauge is placed in the line for obtaining accurate pressure readings. Each furnace and the main line are equipped with Protect-o-Motor Filters. Each furnace is equipped with a bleed-off valve so that the vacuum in any unit can be broken without allowing air to enter the main line. Also, these bleed-off valves are used for admitting inert atmospheres into the furnaces.

The vacuum pump now in use is a Kinney 105 cubic foot per minute, water-cooled pump. This pump is capable of producing a vacuum of about 15 microns pressure. A vacuum of 200-1000 microns is obtainable in the melting furnaces, and this vacuum has been found to be adequate for all large-scale casting purposes.

VII. Water Cooling System

The capacitor bank, vacuum pump, furnace coils, and metal furnace parts must be water cooled. All of this apparatus is equipped with sight drains so that any failure of the cooling water can be seen easily by the furnace operator. Since the capacitors are extremely vulnerable to overheating, their water line is equipped with a water-pressure operated switch which automatically opens the main line circuit breaker in case the water flow through the capacitor bank should become obstructed. Each water feed line is equipped with a stop-cock, so that the correct water flow for any piece of equipment is easily obtainable.

VIII. Casting Technique

When any metal is to be cast into billets which are to be later fabricated into other forms by extruding or rolling, certain defects often found in cast metal must be minimized or eliminated. These defects may be unimportant if the metal is to be used in the "as cast" condition. Since most of the tuballoy castings

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made at Site B are used in subsequent fabrication operations, the general aim of the casting techniques which are described in this report is the production of billets suitable for use as starting material in these forming operations.

The most usual casting defects found in casting of metals are piping and shrinkage cavities. The usual method of minimizing piping, other than avoiding excessively high casting temperatures, involves the controlled cooling of the metal in the mold so that solidification takes place progressively from the bottom to the top of the casting. If solidification occurs in this way, a reservoir of molten metal will be maintained above the solid metal in the mold, as cooling is taking place, and this molten metal will keep filling in the shrinkage cavity formed below it. Therefore a billet cooled in this way should have only a small pipe left at the very top, unless, perhaps, poor mold design might cause conditions which would lead to shrinkage cavities being formed after solidification, but while the metal was still in a plastic condition.

The design of the casting furnaces used at Site B is such that the poured metal is cooled in such a way that piping is practically eliminated. As can be seen in Figures 1 and 2, the crucible in which the tuballoy is melted rests directly on the top of the mold and the top of the graphite mold extends a short distance into the lower part of the induction coil. Both of these factors, together with the fact that heat is removed from the bottom of the mold by the water-cooled bottom plate of the furnace, cause the mold to become hot at the top (from about 900°C to 500°C for a distance of approximately 4 inches from the billet top level), and to remain below 200°C at the bottom before the metal is poured. It then follows that after the metal is poured into the mold, it will cool from the bottom up as it should for pipe elimination. In some cases, the power is left on in the furnace for a short time after pouring the molten metal to be certain that this temperature differential or "hot-topping" effect in the mold is maintained. It has been found that these conditions will consistently either completely eliminate piping or limit the shrinkage cavity to the upper 1½ inches of the billet if it is cast into a mold having no taper from top to bottom. Better results would be expected if a mold having a taper so that the billet was larger in cross-section at the top than at the bottom was used. Somewhat worse results would be expected if big end down molds were used.

In certain cases where complicated shapes are cast, it is often impossible to place the mold in the furnace in such a way that the heating and cooling conditions described above can be utilized. In these cases, the molds are designed with sprues and risers which will contain the shrinkage cavities, and which can be cropped off from the usable part of the casting.

Another type of defect which is quite commonly found on cast metal, is scab-biness. "Scabs" or "cold-shuts" are caused by the solidification of small quantities of metal which may reach a relatively cool mold wall before the level of the main metal body has reached that point. These small pieces of molten metal then become imbedded in the surface of the casting as the mold fills up. This, of course, leaves a scab or pit on the surface of the casting, which is always undesirable, but is especially bad if the casting is to later be used as a rolling billet. In rolling, these scabs or pits tend to elongate in the direction of rolling, and result in seams or slivers on the surface of the rolled metal. At best, this necessitates excessive machining or grinding to produce a perfect surface on the finished metal, or, at worst, these defects can cause seams or cracks which extend deep enough into the rolled metal so as to make the metal entirely unusable.

The minimizing of scabs and cold shuts in the tuballoy castings made at Site B has been found to be aided by several controllable factors. These factors are as follows:

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1. Mold temperature: As has been mentioned above, it is desirable to keep the bottom of the mold as cool as possible to eliminate piping. However, it has been found that if the walls of the mold near the bottom are too cool, cold shuts and scabs near the bottom of the billet will result. Therefore, a balance must be reached so that billets containing a minimum of both piping and scabbiness will be produced. This balance has been found easy to obtain except in a few cases where it was necessary to make long castings of relatively small cross-sectional areas. Except in a few special cases, the proper temperature has been maintained through the entire mold by utilizing the heat from the hot crucible and the part of the mold which extended into the induction coil, and by insulating the outside of the bottom half or two-thirds of the mold with sheet asbestos in order to keep that portion of the mold from remaining too cool.

Often the temperature of parts of molds have been increased by bottom-pouring. This has proven to be especially useful in casting thin-walled tuballoy tubes. When attempts were made to cast such shapes by top-pouring into a cylindrical graphite mold containing a central graphite mandrel for a core, it was found that cold shuts almost always occurred on the inside wall of the tube. If, however, the mandrel was made hollow, and the metal was allowed to pour down through it, and come up through holes at the bottom of the mandrel, satisfactory castings resulted. Thus, the molten metal running through the core had heated it sufficiently to prevent the formation of scabs on the inside wall of the casting.

It should be understood that when the heating of the mold was spoken of in the above discussion, the heating was never carried far enough to raise the temperature of the mold sufficiently to cause the tuballoy and graphite to react chemically. If this is allowed to happen, the casting cannot be removed from the mold without damaging the mold.

2. Careful pouring: Since scabbiness is caused by drops of molten metal splashing against the cool mold wall, and since most of this splashing occurs during the early stages of pouring before sufficient metal has collected in the bottom of the mold to form a pad, the pouring rate is retarded until this pad is formed. This is accomplished by raising the stopper rod very little when the metal is first allowed to run into the mold. In a few seconds, after considerable metal has been poured, the stopper rod is raised high enough to allow the metal to pour into the mold at its maximum rate. This pouring technique is used on all top-poured castings made at Site B.
3. Pouring temperature: Although tuballoy has fairly good casting properties at temperatures very little above its melting point, the foundry work done at Site B has shown that much better castings are produced, especially with regard to surface condition, if the metal is poured at temperatures ranging from 1350° to 1450°C. This rather high casting temperature does not cause excessive piping in the billets, for while the high casting temperature does increase piping tendencies, a more effective hot topping condition is set up because the higher crucible temperature makes for a greater top to bottom temperature differential in the mold.

By using the casting techniques discussed in this report the Site B Foundry has been able to produce tuballoy billets which were satisfactory for extruding

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and rolling. Many other special tuballoy shapes have been successfully cast, but some trouble has been encountered in casting long shapes of small cross section, especially when it was attempted to top pour such castings. The difficulties met with in casting many of these shapes was overcome by bottom pouring.

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FIG. 1: 100 POUND HIGH FREQUENCY VACUUM CASTING FURNACE

1 Stopper Rod Weight	8 Quartz Tube	15 Cooling Water Inlet	22 Steel Stopper Rod Extension
2 Wilson Seal	9 Sillimanite Insulation	16 2" Vacuum Line	23 Water Jacket (Steel)
3 Glass Sight Window	10 Maple Coil Support	17 Graphite Mold	
4 Rubber Gasket	11 Induction Coil	18 Graphite Crucible	
5 Water-cooled Steel Top Plate	12 B+W K 30 Brick Insulation	19 Coil Cooling Water Connection	
6 Rubber Gasket	13 Cooling Water Outlet	20 Coil Power Connection Lug	
7 Transite Lined Plywood Box	14 Water-cooled Steel Plate	21 Graphite Stopper Rod	

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1	Glass Sight Window	12	Water-cooled Bottom Plate
2	Rubber Gasket	13	Replaceable Steel Extension
3	Water-cooled Top Plate	14	Cooling Water Inlet
4	Micarta Tube	15	2" Vacuum Line
5	Maple Coil Support	16	Power Connection Fittings
6	Induction Coil	17	Coil Water Connection Fittings
7	B & W K-30 Insulating Bricks	18	Asbestos Insulation
8	Graphite Crucible	19	Graphite Stopper-rod
9	Graphite Mold (for 4x4x20 lb)	20	Steel Stopper-rod Extension
10	Transite Brick Support	21	Wilson Seal
11	Cooling Water Discharge	22	Lead Stopper-rod Weight

FIG. 2:
300-POUND HIGH
FREQUENCY VACUUM
CASTING FURNACE

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FIG. 3
LAYOUT OF ROOM 104 and PLATFORM IN ROOM-103

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FIG-4
LAYOUT OF ROOM 104 & PLATFORM IN ROOM 103 (VIEWS OF WALLS)

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Figure 5. General View of Furnace Platform

Photograph looking down on the furnace platform from the south end. The top of the 300 lb. mica furnace can be seen at the lower left. The 100 lb. quartz tube furnace and hood is in the position farther along the platform. The control panel is located at the extreme north end. Since this photograph has been taken, an additional 100 lb. quartz tube furnace has been installed in the position between the two furnaces shown above.

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Figure 6. Furnace Platform

Photograph showing the details of the equipment along the east wall of the furnace platform. The furnace cooling water sight drains are placed along the floor, each drain being directly opposite its furnace. The vacuum gauge, and vacuum bleed-off valves for each furnace can be seen directly above the sight drains (the third valve from the right is connected to the argon tank so that an argon atmosphere can be introduced into the furnace). The McLeod gauge for accurately reading the pressure in the vacuum system is located on the brick wall just out of the field at the lower left of the picture.

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Figure 7. Floor Level Under Platform

a view below the furnace platform. The portable stacker is in position under the 500 lb. micarta furnace. The furnace bottom-plate and a mold are on the stacker platform, preparatory to being raised up into the furnace. The filters on the vacuum lines of each furnace position are visible further to the rear. The 100 lb. quartz tube furnace does not extend below the platform joists, and thus is not visible in this view.

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Figure 8. Motor-Generator Room

General view inside the generator room. The large piece of equipment in the left-foreground is the high frequency motor-generator set. The capacitor bank and capacitor control relays are located in the cage just behind the motor-generator set. The main vacuum pump can be seen in the back corner of the room. The large box on the wall above and to the right of the pump is the auto-starter for the motor-generator set. The trough just below the window collects the cooling water discharge from the capacitor bank and vacuum pump. The trough is fitted with a glass front so that the drains are visible both from the fur face platform (through the window, and from the floor of the generator room.

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