Trends in Vacuum Precision Casting

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INTRODUCTION

Vacuum precision casting furnaces have served the needs of aircraft engine parts producers for high performance nickel-based and cobalt-based superalloys for many years. Recent updates on vacuum investment casting furnace design have covered the developments of microprocessor-based and micro-computer based control. Accurate, repeatable control, plus refinements in equipment design and operation have given casters the tool needed for maximizing yield, maintaining material purity, and developing higher strength temperature products. A combination of factors has resulted in the need for larger vacuum precision casting furnaces with the necessary design features required to accommodate larger melts and castings.

STATE OF THE ART FURNACES

The state-of-the-art furnace is typically a 50-pound vacuum induction melting unit furnace which can be termed a "three-in-one" furnace (Fig. 1). It gives the operator the choice of casting in the equiax mode, the directional solidification mode, or the monocrystalline mode (Fig. 2). This single furnace is designed so that an operator only has to press control buttons to vary the casting mode. For example, for the directional solidification mode, the DS coil and the mold withdrawal program is energized. For the equiax mode, the mold elevator is programmed to rise and lower quickly, while for monocrystalline castings, another pre-selected sequence is used.

These furnaces are, for the most part, programmable- controlled designs using industrial programmer controllers made by Allen Bradley, Honeywell, and others (Fig. 3). The more accurate control they provide makes possible exact repeatability from casting to casting. Carrying this feature one step further, micro-computers (and there are several installations now in service) provide the capability of controlling all facets of a precision investment casting operation. The operator can input heat number, the alloy designation, the casting part number, and as much additional information(even his name) as desired. During the melting and casting operation, the process parameters are recorded and are available for future reference in connection with any specific casting number for quality assurance purposes.

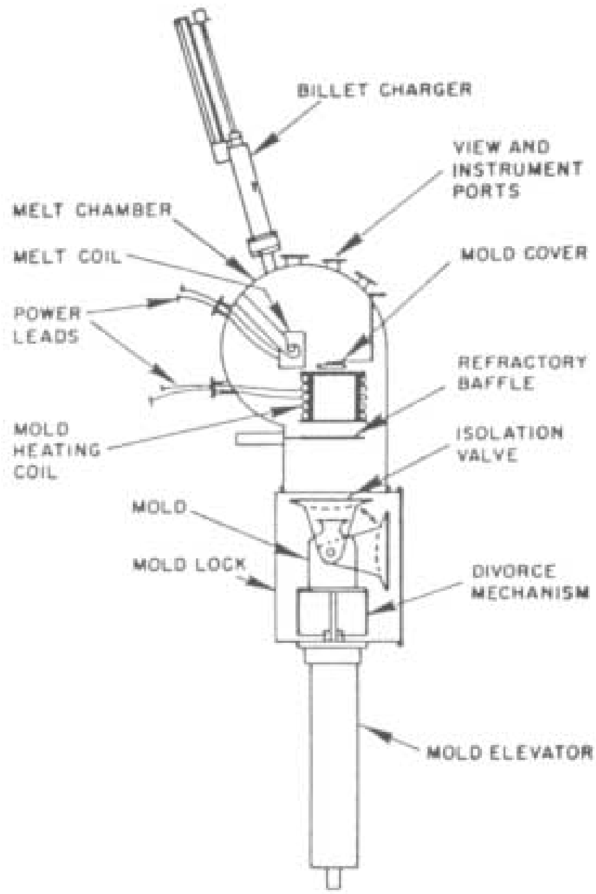

Figure 1 - Vacuum Precision Casting Furnace with directional solidification capability - front elevation.

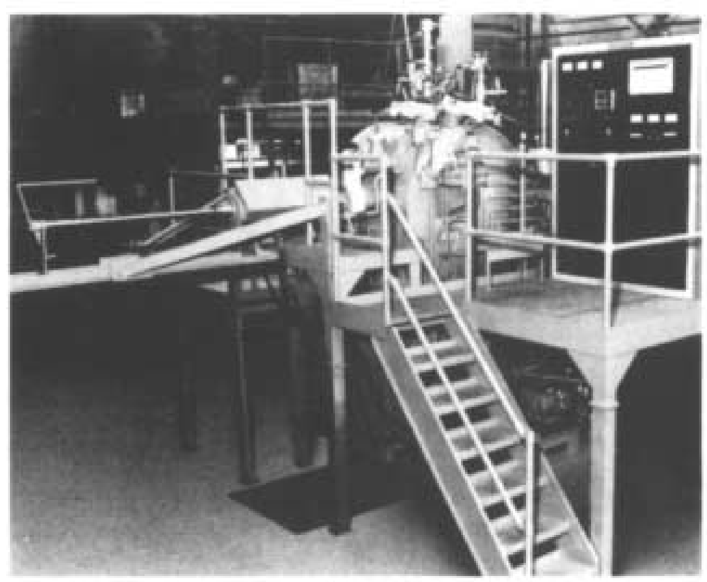

Figure 2 - Vacuum Equiax Casting Furnace with horizontal charger.

Figure 3 - Microcomputer control for Vacuum Precision Casting Furnace.

AUTOMATIC OPERATION

One may ask whether precision and vacuum investment casting furnaces are being used in a completely automatic mode. They are being used in an automatic mode, but the furnaces are not automated. Automated equipment would immediately pinpoint an area of equipment failure, make the component repair and continue operation. As presently designed, automatic furnaces will stop if there a failure in a component such as a vacuum valve and sound an alarm. Maintenance personnel would then be required to pinpoint the area of failure and to take the corrective action.

Automatic furnaces, as presently manufactured, work in the following way: The operator first performs three manual operations. the billet is manually charged so the furnace can be inspected; next, an empty mold is loaded on the mold platen in the load lock (after the previously filled mold is removed); finally, the "start" button is pressed. The rest of the furnace operations are controlled automatically, either from the programmable controller or the computer system until it is time to unload the next casting.

TREND TO LARGER CASTINGS

With reliable designs available and automatic casting furnaces in operation, several significant factors point the way to the next developments in furnace design. The rate at which the technology of vacuum investment casting is changing is increasing. As new techniques are developed, casters are building on that knowledge and the next steps are coming faster and faster (Fig. 4). Past developments such as directional solidification and single crystal are now state-of-the-art. Alloy compositions have been refined and are in production.

In commercial aviation, higher performance components are being used to extend the service life of the jet engine. The significant advances in blade and vane life have generated similar needs for other jet parts to last as long.

Bearing housings, burner cans, compressor cases, turbine cases, and exhaust cases were all at one time fabricated from materials by welding. Strength and creep property limitations of this class of fabricated components are now being overcome by moving to castings which will withstand higher temperatures.

The technology for making bigger, thinner and better castings is still evolving. Vacuum precision investment casting furnaces with 300 to 500-pound capacity are aimed toward making these larger parts (Fig. 5). A typical casting, a 36" in dia., 9" high ring with a very thin cross-section, weighs about 75 pounds and will require a melt on the order of three and one-half to four times its weight, or up to 300 pounds (Fig. 6). These high cast to finished weight ratios are caused by the combination of the additional sprues, runners, and the necessary higher hydraulic head required to drive the metal into the mold. So it is anticipated an average 3.5:1 cast to finished

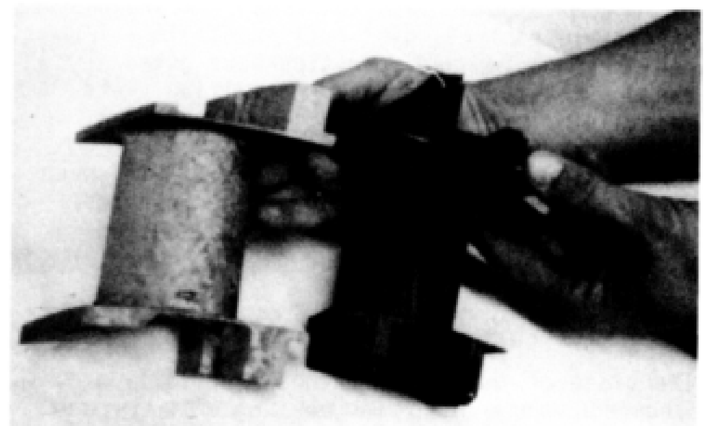

Figure 4 - Equiax and D/S turbine blade castings.

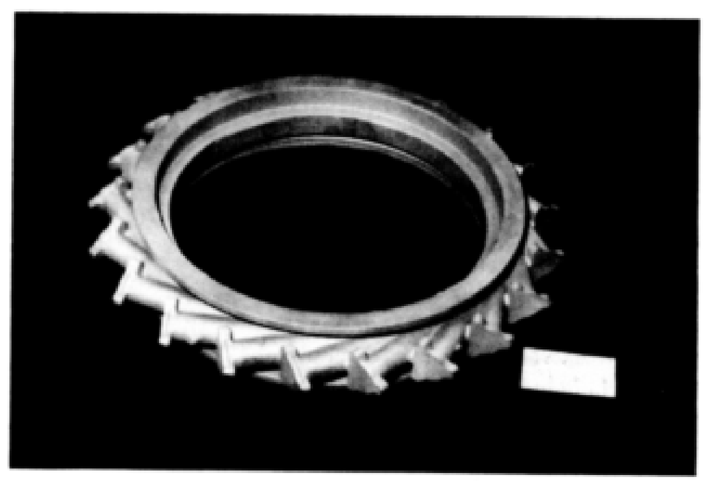

Figure 5 - Example of a large vacuum integral casting.

Figure 6 - Example of a large vacuum integral casting.

weight ratio will be required due to the complexity of the castings themselves and the design of the molds (Fig. 7). This, incidentally, will lead to more scrap and revert, the re-cycling of which is now also being addressed from the standpoint of cleanliness (which is a subject involving other furnace technologies).

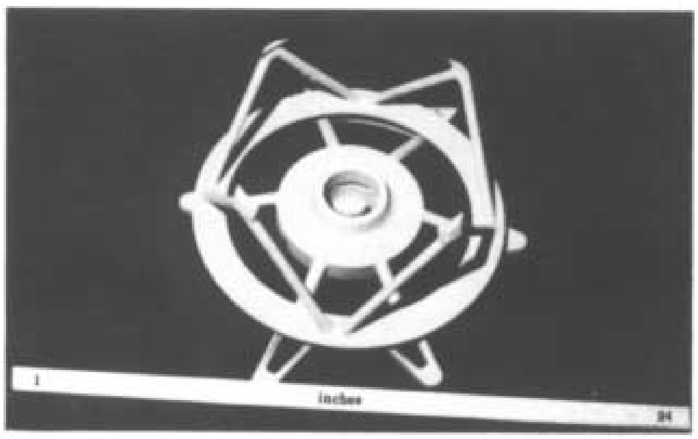

Figure 7 - Example of a large vacuum integral casting.

The technology for producing these larger castings has been helped by improved techniques for making wax patterns (Fig. 8). In making

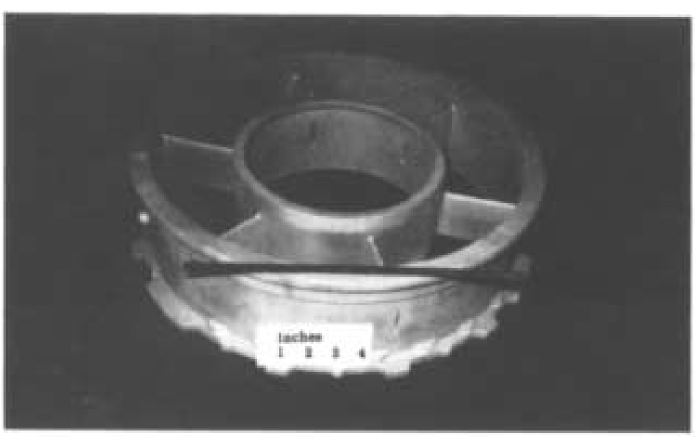

Figure 8 - Example of a large vacuum integral casting.

patterns for any one of these large structural castings, three or four different kinds of waxes may be used because of their differing expansion characteristics when injected and their differing reactions with the shell materials (Fig. 9). Examining a big structural casting mold pattern, some plastic and some wax components might be found.

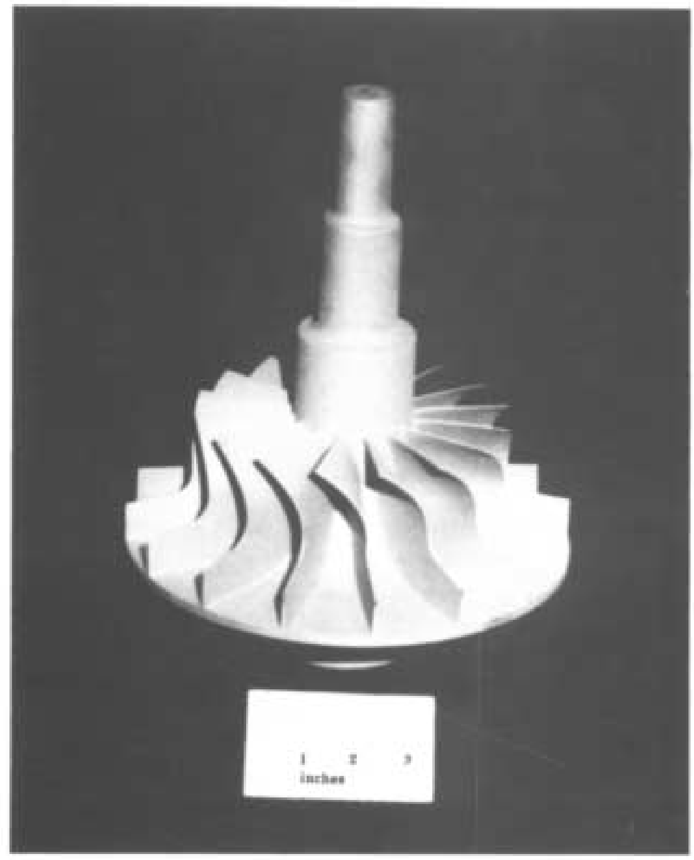

Figure 9 - Example of a large vacuum integral casting.

The resulting large molds (Fig. 10), for example up to 53" dia. x 36" high, require larger mold locks on the semi-continuous vacuum precision casting furnaces and additional high speed pumping capacity to evacuate the locks before moving the mold into the melting chamber (Fig. 11).

Figure 10 - Example of a large vacuum integral casting.

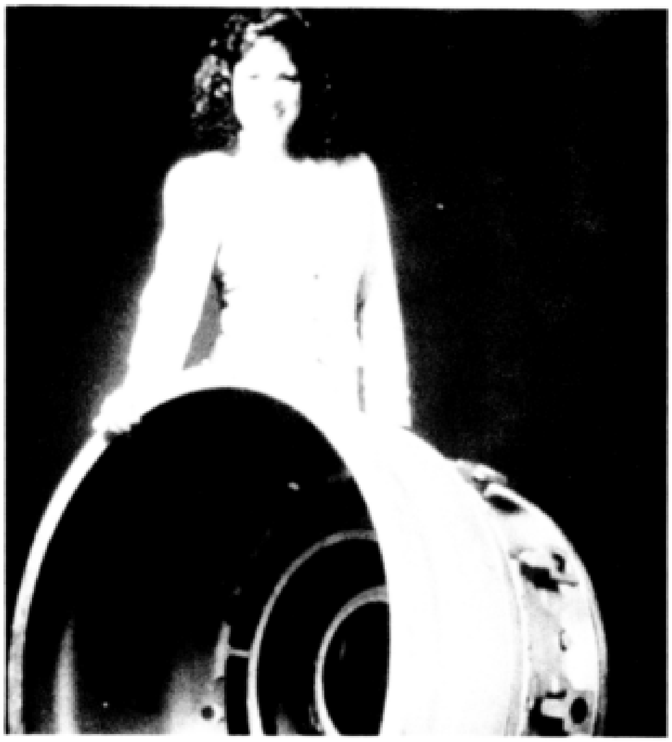

Figure 11 - Example of a large vacuum integral casting.

FURNACE DESIGN FEATURES

Vacuum precision casting furnaces for larger castings have features very similar to the 50-pound furnaces in use today, and will be able to accommodate the unique requirements of the larger molds and materiel delivery systems. Whereas molds for a 50-pound precision investment casting furnace might weigh 30 pounds, molds for the larger castings may weigh up to 500 pounds. Again, if a 50-pound furnace takes a minute to pump down the mold lock and a target time of two minutes is desired for the 500 pound mold furnace, the incremental pumping capacity to handle the additional outgassing is significant (Fig. 12).

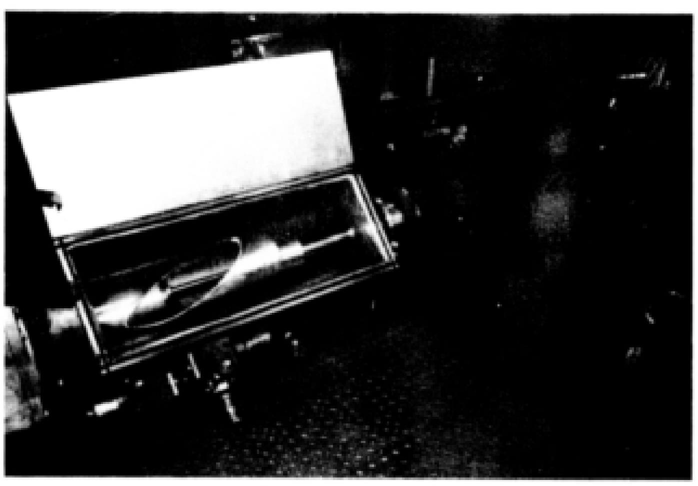

Figure 12 - Horizontal charger for Vacuum Precision Casting Furnace.

Billet charging will move from the horizontal plane, which is typical in the case of 50-pound furnaces, to the vertical plane in the case of 300 to 500 pound furnaces.

Additional handling equipment is required to move the pre-alloyed billets from the floor to the top of the furnace for vertical loading (Fig. 13).

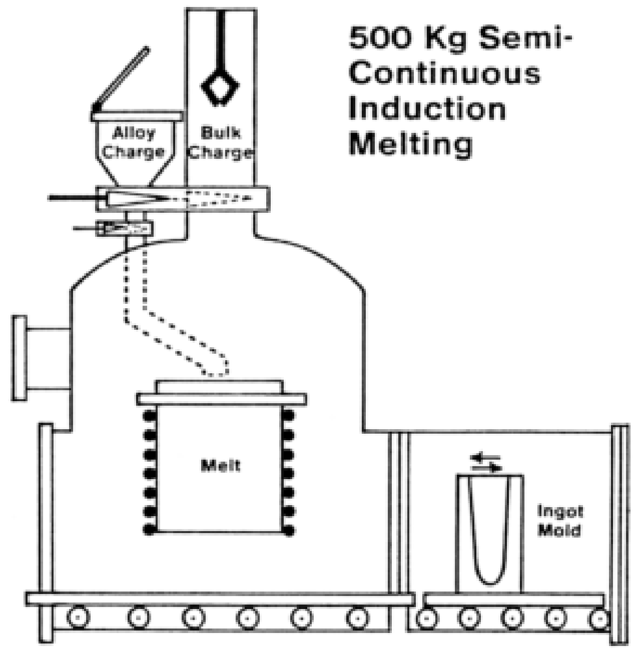

Figure 13 - Typical 1000lb Semi-Continuous Vacuum Induction Melting Furnace.

When pouring into large molds to produce cast rings 36 to 40 inches diameter with .040 in. wall thicknesses, the caster's job is to completely fill the ring and make the metal flow through numerous gates and risers and a .040 in. filter. To fill the mold in order to provide a part with adequate structural strength without any cross-sectional boundaries, the furnace will have to provide the ideal pouring temperature and an accurately pre-heated mold. The metal has to be cool enough during solidification for multiple grains to form.

The next generation of larger precision casting furnaces will also have accurately controlled profile pouring, which is pre-set manually and then programmed to repeat automatically.

Designs are similar to those used on existing 50-pound units (Fig. 14). Hydraulically operated tilting mechanisms are used for the smoothest pouring operation. Profile pour programs have resulted in increased yields in current furnace operations; up to 95% yield for equiax castings (Fig. 15). In a typical equiax pour, a constant stream of molten metal should flow over the lip of the crucible to hit a constant spot in the pour cup of the mold. To achieve this, the tilting action must start with a slight acceleration, followed by decelaration,

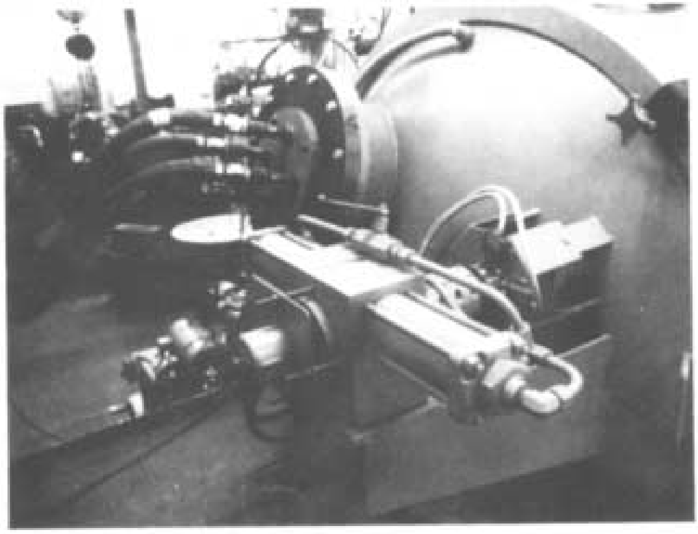

Figure 14 - External furnace tilting actuator.

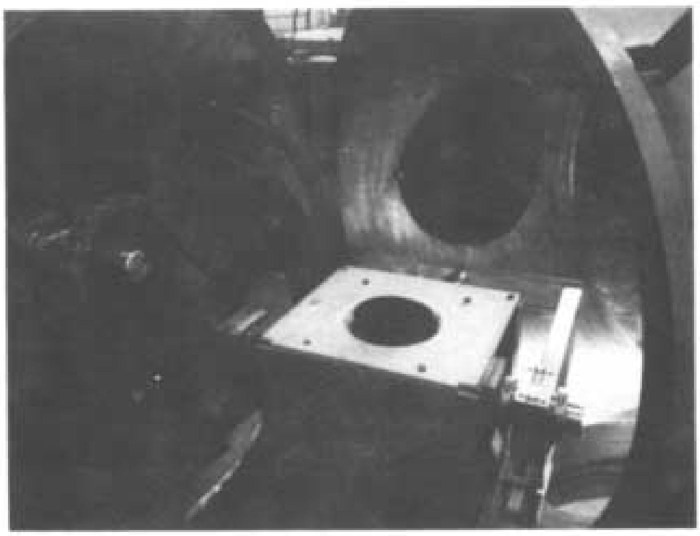

Figure 15 - Internal tilting mechanism and induction furnace.

then additional acceleration and, finally, more acceleration resulting in a constant head of molten metal behind the pour stream. The repeatability of pouring is most important in equiax casting (Fig. 16). The profile pour is initially set up by the operator by keyboard entry using a programmable controller or, alternatively, with manual input using the teaching mode on the computer. The teaching mode is used to encode the physical motions generated by the operator manually, after which the controller will generate signals to repeat the same motions. During the simulation in the teaching mode, white sand is used as a substitute for molten metal.

Filtering was mentioned as a critical consideration for larger castings with thin walls. While pour-cup filters are presently being used for 30-pound castings, additional filters will be used on larger castings for the

Figure 16 - Vacuum Precision Casting Furnace operator's control station with microcomputer.

individual runners. The technology of molten metal filtration is advancing rapidly also. Filters, however, slow down the flow of molten metal, and therefore, delay the arrival of hot metal at the mold. To avoid solidification in the runners or in the sprues, pre-heat coils may be required for melts which have to pass through a honeycomb filter.

SUMMARY

The primary considerations for precision vacuum investment casting of high performance parts have been material quality and yield. These same considerations apply to larger structural castings with additional considerations of economics and performance. Structural castings are made from existing nickel base and high corrosion resistance alloys The use of these alloys for structural components because of their better performance and greater economy is the new development.

The aircraft turbine engine industry is presently the end user for all the large vacuum precision cast parts being manufactured. As this technology continues to evolve, we can expect to see other industries that require the same degree of material quality, performance capabilities, and economical yield looking into these types of casting. As the technology evolves, the equipment manufacturer will be ready with the high performance furnaces needed.

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