Vacuum Industries Incorporated

TECHNICAL NOTE

# EQUIPPING FOR DIRECTIONAL SOLIDIFICATION

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**IN BRIEF:** Directional solidification holds promise for applications other than just aircraft jet engine turbine blades. Equipment for directional solidification must provide precise control of temperature, atmosphere, and cooling rate as well as control of the temperature gradient from bottom to top of the mold cavity. Such equipment now is available, making directional solidification more than a laboratory curiosity.

■ A METALLURGICAL technique that currently has its primary application in investment casting finishing is becoming increasingly interesting for other high-performance foundry applications.

That technique, variously referred to as controlled solidification or directional solidification, has been developed to its present state for the manufacture of aircraft jet engine turbine blades. Generally, directional solidification is applied to metal involved in high-temperature performance when thermal shock is a significant problem. Other possible applications of the technique include casting of magnetic materials, semiconductors, nonmetallics, laser crystals, and other cast parts in which gain in physical properties is desired along one principal axis.

Numerous papers in technical and scientific journals have appeared in recent years on the metallurgical aspects of directional solidification. The purpose of this article is to examine the equipment requirements for a typical directional solidification melting furnace.

**Elements of Operation**—Briefly, directional solidification produces a high-strength, oriented-crystal alloy part. Solidification of the material is controlled so that investment castings possess ductility and thermal shock resistance, increased axial strength, and greater creep resistance.

**High-Temperature Alloy** — Parts cast to size by investment casting operations are produced with oriented grain boundaries through the use of vacuum induction melting furnaces equipped for the precise control of temperature and cooling rate that is necessary for directional solidification.

A typical directional solidification furnace may have a melt capacity of 17 to 50 lb. It must be equipped not only for precise control of temperature, atmosphere, and cooling rate, but also with accessories that establish and gradually change the temperature gradient along the mold axis—hot at the top, cold at the bottom—so that the bottom of the casting "freezes" first, and the solidification front moves gradually to the top of the mold. Motion of the solidification front is very slow, akin to the rate required in crystal growing.

The most successful method of producing the necessary grain orientation in a cast part is to maintain the upper part of the mold at an extremely high temperature (somewhat above the teeming temperature) while the lower portion is highly chilled. This goal requires a mold that is open at the bottom and is resting on a chilled platen. The platen moves on the load elevator mechanism, in and out of the induction-powered mold heater.

A typical rate for "pulling" the casting is several inches per hour, making it necessary for the load elevator, on which the mold is mounted, to move at closely controlled, highly reproducible speeds.

The requirements for precision movement and for providing space for a second induction heater generally will preclude the possibility of modifying existing equipment. A careful examination of the total system involved will favor the installation of new equipment.

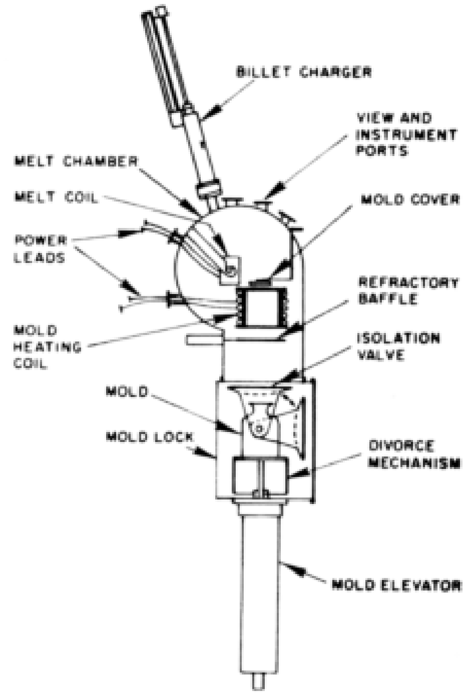



*Fig. 1—Schematic diagram identifies major components of a directional solidification induction furnace system.*

**Definitions** — Before discussing a typical directional solidification furnace, let's establish definitions of terms associated with this type of furnace design. Refer to Fig. 1.

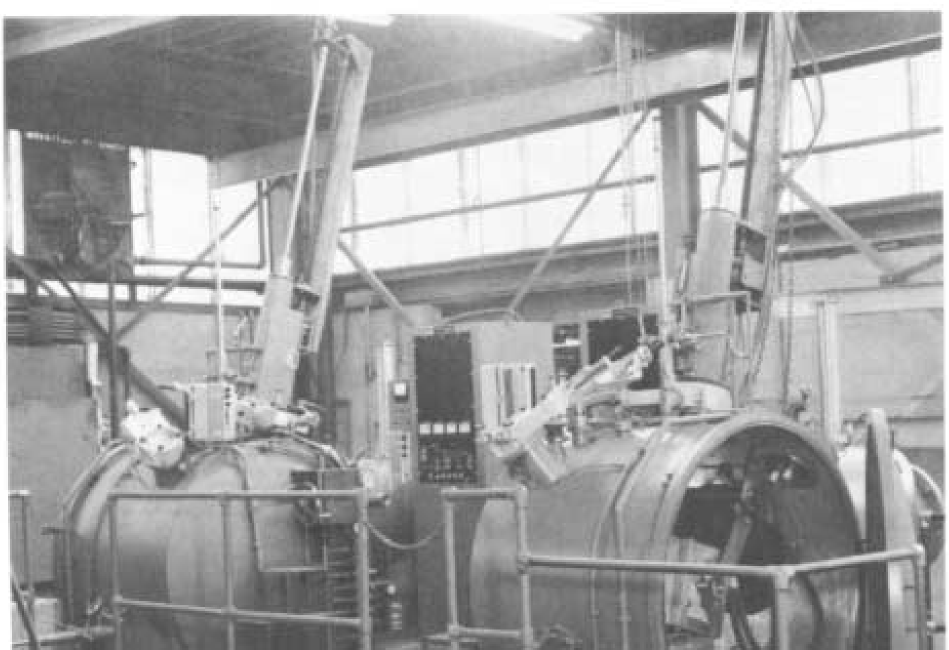
*Melt Chamber*—A vacuum chamber in which the induction melting furnace and mold preheat coil are situated.

*Mold Lock*—A vacuum chamber beneath the melt chamber that can be separated by closing the *Mold Lock Isolation Valve.*

*Mold Elevator*—Normally situated beneath the mold lock, it has a variable slow speed for "pulling" the mold and a fixed speed for convenient positioning. It raises the

*Fig. 2—Operator loads a billet into the billet charger. Note valved operator's view port, immersion thermocouple, and miscellaneous controls.*

*Fig. 3—Overall view of a two-furnace system shows ready accessibility of operator controls. Door on furnace at right is open to show melting coil and mold heating coil. Mold lock is below floor level shown here.*



mold from the charging position in the mold lock through the isolation valve to the pour position in the melt chamber.

*Mold Heating Coil*—Situated between the melt coil and mold charging position, this unit is an induction coil with necessary refractory and graphite susceptor. It heats the mold to temperatures above the melting point of the alloy.

*Billet Charger*—Situated on the melt chamber, it permits charging a prealloyed billet into the induction furnace without disturbing the vacuum.

*Melt Chamber Pumping System*—Generally consisting of a diffusion pump and a combination mechanical roughing and fore pump, it produces melt chamber finishing pressures in the 10[illegible] torr range.

*Mold Lock Pumping System*—Usually a mechanical blower and roughing pump package.

*Vacuum Control Panel*—Houses vacuum controls on a graphically displayed schematic panel. Also houses necessary vacuum and temperature instrumentation.

*Induction Melting Power Supply*—Required to power the melting coil.

*Mold Preheat Induction Power Supply* — Required to power the mold preheat coil.

*Divorce Mechanism* — Permits separating a mold from the water-cooled mold platen while the mold is in the preheat position.

*Refractory Baffle*—A refractory gate that automatically is inserted between the mold and the chill platen while the mold is in a preheat position and divorced from the chill platen. It prevents evaporated deposits on the mold from the mold chill platen.

Other components that can be considered conventional are valved operator's sight ports, optical instrumentation ports, and valved immersion thermocouple assembly, for example.

**Operating Sequence** — Operation of a typical directional solidification furnace generally follows a sequence:

A mold is removed from the mold lock, the mold lock isolation valve is closed, the melt chamber is under vacuum, and the mold lock is at atmosphere with the mold elevator in the withdrawn position. A prealloyed billet is placed in the alloy billet charging mechanism, which is evacuated to approximately 50 microns.

Subsequently, the billet charging valve is opened and the billet placed within the induction melting furnace. Power is applied to the melt coil until a molten state is achieved.

During the time that the melt is being processed, a preheated mold is placed in the mold lock, which also is evacuated to approximately 50 microns. The mold lock isolation valve is opened, and the mold elevator mechanism lifts the mold into the mold heating coil. The divorce mechanism is actuated, and the refractory baffle is inserted. Full power then is applied to the mold coil, driving the mold from its preheat temperature to the temperature at which the mold is ready for teeming.

Optical pyrometer readings are taken on the melt to insure the correct teeming temperature. The refractory baffle is withdrawn, and the mold chill platen is raised in contact with the mold. The pour then is made. Fig. 3 shows the melting furnace and mold preheat coil.

### Mold Withdrawal

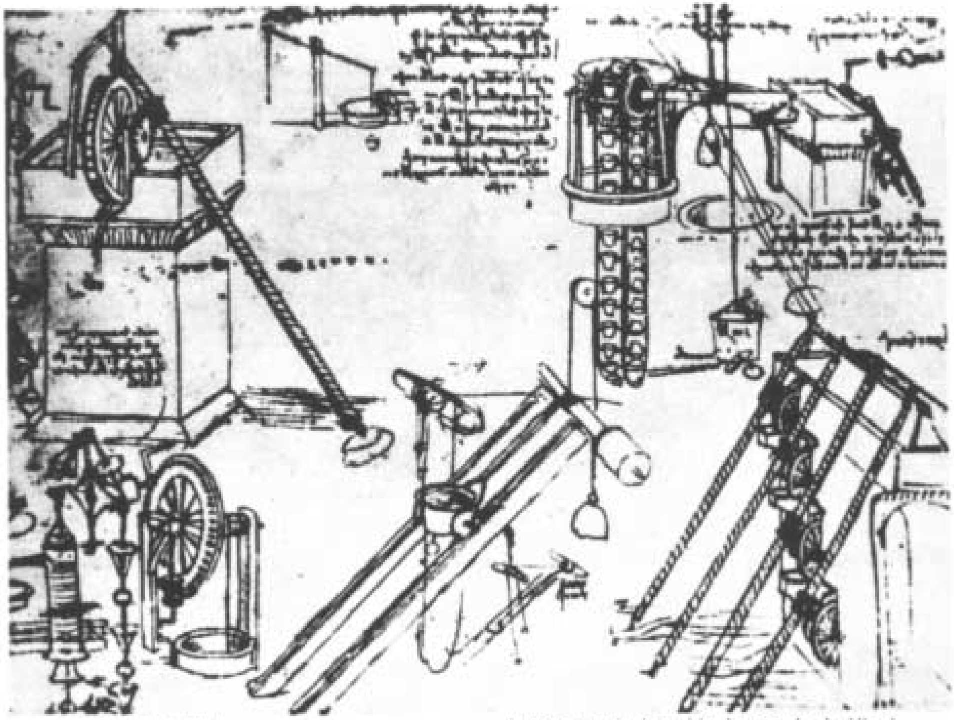
At this point, the mold begins its slow withdrawal from the mold preheat coil. After withdrawal has been completed, and the casting is solidified, the elevator is shifted into its high-speed mode, and the mold is moved into the mold lock. The isolation valve is closed, the mold lock is vented to atmosphere, the door is opened, and the poured mold is removed.

Meanwhile, another ingot has been charged into the melt coil, and the cycle is repeated. The furnace, having received its charge, is ready for pouring into the next preheated mold.

When the isolation valve is open, the entire system is operating in the $10^{-4}$ torr range. That procedure permits the refractory mold to be totally outgassed at maximum temperature prior to pouring and minimizes the possibility of gas entrapment.

**Promising Future**—Metallurgical process research, such as that conducted for more than seven years at Pratt & Whitney Aircraft Div., United Aircraft Corp., indicates that there is a promising future for directional solidification in manufacture of cast superalloys. Design and engineering now may establish requirements for parts that utilize fully the mechanical properties of oriented single crystals.

With the advent of commercially available furnaces designed expressly for directional solidification of precision castings, the technique has crossed the threshold from a laboratory curiosity to a production workhorse that should find many new applications.



BETTMANN ARCHIVE — Machinery designed by Leonardo da Vinci.

# da Vinci had the right ideas but no vacuum melted alloys

Had Leonardo waited another 400 years, Vacuum Industries' continuous or batch induction melting and casting furnaces could have helped get his designs off the drawing board.

The mold elevator, for example, in our newest precision casting furnace for superalloys, withdraws the casting from the hot zone at a predetermined rate. It provides optimum control for directional solidification of alloys, needed for strength and high-temperature performance.

The swing-away mold lock isolation valve protects the mold from falling dirt, decreases mold lock volume and lessens pit depth – features which reduce rejects and cut investment costs.

The unique melt chamber design offers convenience in locating accessories, provides efficient cooling and minimizes downtime.

If new advancements in vacuum processing of alloys, directional solidification, precision investment casting or specialized ingot production could help turn your ideas into new products, look to the innovators in vacuum induction melting and casting furnaces . . . Vacuum Industries. Systems for a few grams or tonnage quantities. Send for performance data and our latest brochure.

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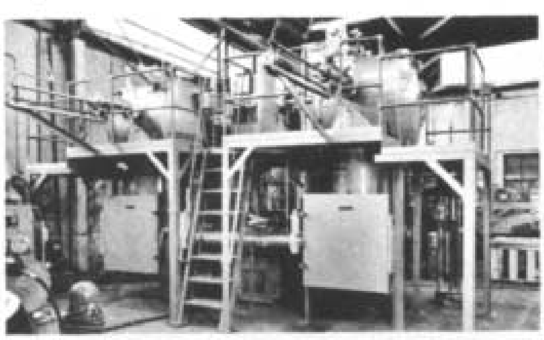

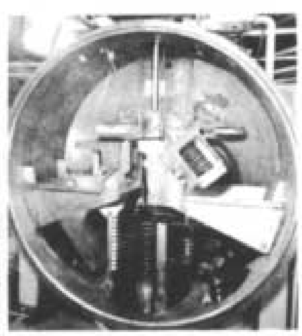

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