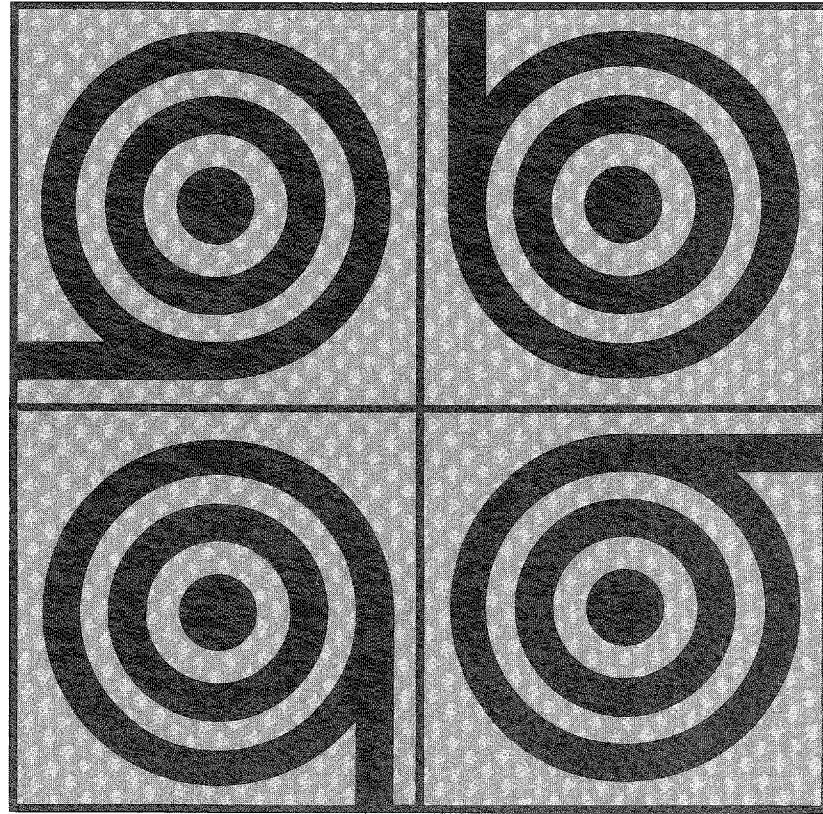


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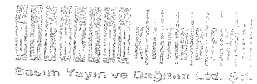
Centrifugal Casting



Nathan Janco



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Nathan Janco is universally acknowledged as a pioneer in the field of casting machine design and one of the foremost authorities on the subject of centrifugal casting.

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Nathan Janco holds several U.S. patents and is the designer of numerous horizontal, vertical, and face-plate machines, as well as special purpose machines for high production. He has pioneered the centrifugal casting of plastics, magnesium sludge, uranium and titanium, in addition to centrifugal vacuum casting. His articles appear frequently in the American Foundrymen's Society *Transactions*.

DEDICATION

To the memory of my beloved son, Steven Harris Janco, who was to have been
my successor in The Centrifugal Casting Machine Company before his untimely death
on February 27, 1980.

ACKNOWLEDGMENTS

We wish to thank the following for their contribution to this publication: American Crucible Products, Lorrain, Ohio (Table 14-1); Janney Cylinder Co., Wilmerding, Pennsylvania (Fig. 14-1); Stooddy Company, City of Industry, California (Fig. 14-2); U.S. Pipe and Foundry Company, Burlington, New Jersey (Table 14-3, Fig. 16-1); *Iron Age*, January 3, 1983 (Fig. 2-11).

We also wish to thank The Centrifugal Casting Machine Co., Inc., Tulsa, Oklahoma, for their participation and cooperation in publishing this book.

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What is Centrifugal Casting?

INTRODUCTION

Casting is the process whereby liquid or molten material is poured into a mold and permitted to solidify. The mold and casting are then separated from each other. Cast materials can be either metallic or nonmetallic; however, in this book we are primarily concerned with metals.

Molds are frequently made of sand or other ceramic materials, although they may also be made of metal or carbon (graphite). The latter type of mold, whether metal or graphite, is referred to in the USA as a "permanent mold" because it is reusable for making a large number of castings. Ceramic or sand molds, by contrast, produce only one cast of metal and are then destroyed; new molds must be made for each cycle of casting.

CENTRIFUGAL CASTING VS. FORGING AND STATIC CASTING

The facilities required for centrifugal casting are not elaborate but somewhat more expensive than those required for static casting. However, the smaller floor space requirements of centrifugal casting may offset its greater initial expense.

At this writing, centrifugal casting continues to concentrate in its specialty fields: highly engineered castings, the mass production of pipe and tubes, fittings, high alloy turbine blades, jewelry and dental parts, and other precision castings.

Automation and other efficiencies of the large producers has pretty well phased out small, incidental, or independent sand foundry competitors. Most centrifugal foundries have complete machine shops, heat-treating facilities, and special melting equipment, along with complete testing facilities to meet customers' high quality demands.

On the average, initial equipment investment is highest for forging and for extruded material and lowest for static sand casting, with centrifugal lying between, competing with both.

Centrifugal tubes can be made on an individual basis to such customer requirements as outside diameter, wall thickness, alloy type, and machined condition. Flanges and irregular contours, which are not always profitable as forg-

ings, can be cast centrifugally, and casting yield is considerably higher than that with static methods. Centrifugal castings can also be welded with static castings to make cylinders, rolls, etc., at a savings compared to one-piece constructions.

CENTRIFUGAL CASTING PROCESS

The process for centrifugal casting differs from static casting in that the mold itself is spinning during the time the casting is solidifying. Centrifugal castings are usually poured while the mold is spinning; however, for certain applications, particularly in the case of a vertical casting, it is sometimes preferable that the mold be stationary when pouring begins. The machine then accelerates the speed of the rotating mold either during the filling of the mold or after completion of pouring. In other cases, such as horizontal centrifugal casting, it is often desirable to have the mold rotating at a lower speed during pouring, followed by rapid acceleration to a higher speed during the solidification period. The application of centrifugal force to a metal as it solidifies can be used to achieve a dense, sound casting. To understand why this is so, it is necessary to consider metal solidification behavior.

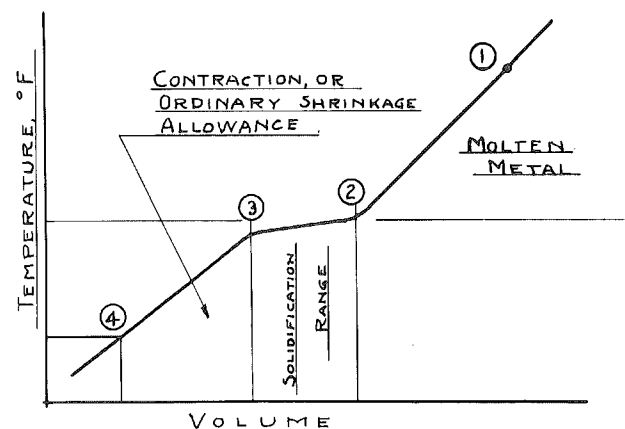


Fig. 1-1. Changes in volume resulting during solidification.

Shrinkage

Most metals and alloys, when changing from the liquid to the solid state, undergo a reduction in volume referred to as "solidification shrinkage" (points 2 and 3, Fig. 1-1). The extent of this shrinkage is often quite significant, usually amounting to 5% or more. Unless precautions are taken in the production of castings, this type of shrinkage can manifest itself as either localized or distributed cavities inside the solidified casting.

In static casting operations, it is customary to incorporate risers (or feeders) into the design of the mold cavity. These supplemental masses of metal, usually attached to the heavier casting sections, are intended to solidify last and to provide "feed" metal to the casting at locations where internal shrinkage cavities would normally develop. It is intended that such cavities should form within the risers themselves, the latter being cut off and discarded for remelting. However, if risers are not (or cannot) be correctly designed and located, then the casting will usually have a series of localized or dispersed internal shrinkage cavities in the last sections to solidify. Such defects not only reduce mechanical strength and other properties, but may also constitute cause for rejection of the part. Figure 1-2 illustrates the solidification of a cube of pure aluminum. Views (a) through (c) show how a localized shrinkage cavity has formed within

the casting as a result of solidifying from the outside walls inward. This behavior is representative of most pure metals or alloys having a narrow solidification range.

Many alloys have a wide solidification range, passing through a rather extended "mushy" condition as they change from liquid to solid. In such cases the internal shrinkage is much more dispersed and often results in a spongy condition, sometimes not readily visible to the naked eye. This dispersed shrinkage will likewise reduce mechanical properties and is a major cause of leakage under hydraulic or pneumatic pressure.

The foregoing shrinkage in volume ceases when the last portion of the casting has solidified. At this point the casting, although it conforms to the dimensions of the mold cavity, is still at a very high temperature. As it subsequently cools to room temperature, there is a further contraction in both volume and linear dimensions of the part (see view (f), Fig. 1-2). Unless the mold cavity is initially made larger than the size of the specified finished casting, the part will be under-size. Thus, an allowance must be made for the contraction of the casting after it has solidified and subsequently cools to room temperature. This is known as the "pattern allowance" or "patternmaker's shrinkage allowance" and depends on pattern geometry, metal cast, and method of casting (See Table 1-1).

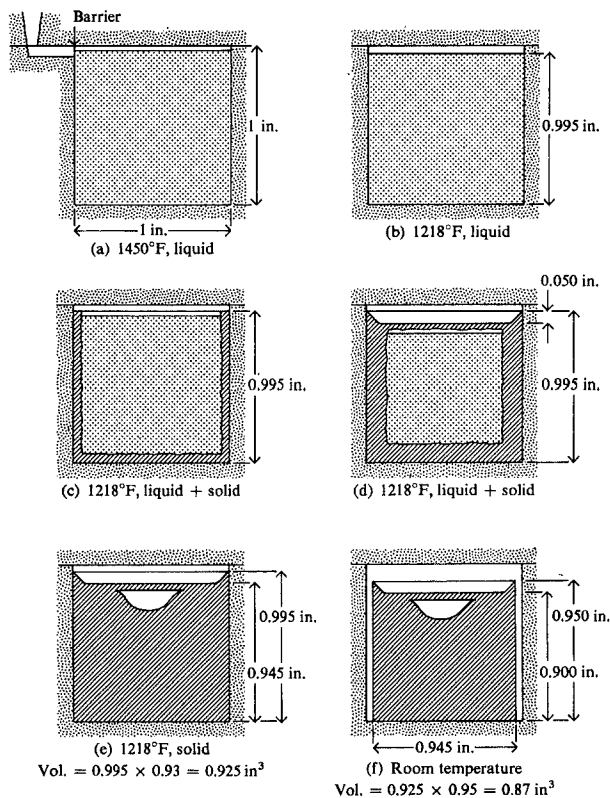


Fig. 1-2. Contraction of an aluminum cube during slow cooling.

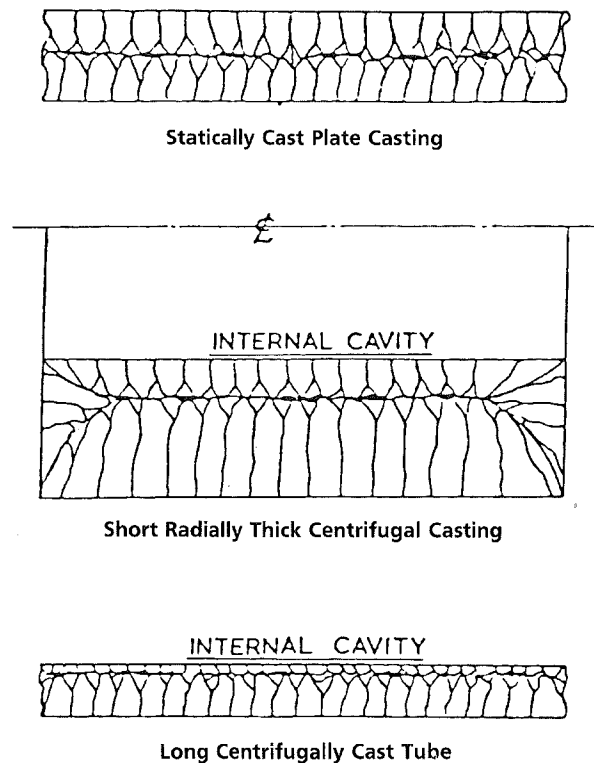


Fig. 1-3. Solidification behavior of three different castings.

METHODS OF CENTRIFUGAL CASTING

Before discussing the various methods of centrifugal casting processes, it should be noted that there are two basic classes of centrifugal casting machines: vertical and horizontal; these terms relate to the position of the rotational axis of the machines. Details of the various kinds of machines will be covered in Chapter 2: Types of Machines. As will be seen, some types of castings are more suited to one type of machine than another.

Generally speaking, there are three methods for the utilization of centrifugal force for casting. All are loosely referred to as "centrifugal casting," though more specifically we can distinguish between them as follows.

Method I—True Centrifugal Casting

Where no core is used, essentially all of the heat is extracted from the molten metal through the outer mold wall. The poor thermal conductivity of the air in contact with the internal diameter results in little heat loss from this direction. Thus, we obtain perfect directional solidification from the outside inward (lower view, Fig. 1-3) and grain growth is typically columnar (Fig. 1-4). Because of favorable thermal gradients, in addition to the outward centrifugal force acting upon the molten metal, each successive increment of metal to solidify is fed by the residual liquid metal in contact with it until solidification is complete. Under proper conditions, shrinkage porosity is non-existent.

Table 1-1.
Patternmaker's Shrinkage Allowances

CASTING ALLOY	ALLOWANCE PER FOOT
Aluminum alloys	5/32 inch
Aluminum bronze	1/4 inch
Brass, yellow (thick).....	5/32 inch
Brass, yellow (thin).....	3/16 inch
*Cast iron, gray.....	1/10 to 5/32 inch
Cast iron, white.....	1/4 inch
Tin bronze.....	3/16 inch
Gun metal.....	1/8 to 3/16 inch
Lead.....	5/16 inch
Magnesium.....	1/4 inch
Magnesium alloys (25%).....	3/16 inch
Manganese bronze.....	1/4 inch
Cupro nickel.....	1/4 inch
Nickel.....	1/4 inch
Phosphor bronze.....	1/8 to 3/16 inch
Steel (carbon).....	3/16 to 1/4 inch
Steel (chromium).....	1/4 inch
Steel (manganese).....	5/16 inch
Tin	1/4 inch
Zinc.....	5/16 inch
*The amount of shrinkage in cast iron depends chiefly upon the speed with which the casting cools, greater shrinkage resulting from more rapid cooling, and vice versa.	

Table 1-2. Applications for Centrifugal Castings

Bearings, bearing bushings and cages	Hollow extrusion billets	Rocket and missile fins
Brackets	Hydraulic and pneumatic cylinder tubes	Rollers and rolls
Brake drum liners	Impellers and blades	Sealing rings and metal O-rings
Cylinder liners	Investment castings	Sewage pipe and soil pipe, cast iron as-cast condition
Dam gate hoist cylinders	Jaw clutches	Shells for canned motor pumps
Dental prosthetics	Jewelry (gold, silver, platinum, pewter and bronze)	Sleeves
Ductile iron pressure pipe for water and gas, as-cast condition	Meter bodies and liners	Snorkel tubes
Electric motor rotors (aluminum and bronze)	Nozzle boxes	Stator shells for atomic power
Electronic module cases and covers	Paper mill rolls and drums	Steel mill rolls, bi-metallic and mill roll sleeves
Flanges	Piston rings and piston inserts	Structural columns
Furnace and oven rails	Pressure vessels	Submarine masts
Gas turbine rings	Pulleys and sheaves	Tees for piping connection nuts
Gears, gear blanks, including bi-metallic	Pump liners, including bi-metallic	Textile rolls
Gun slide liners and bearings	Pump rotors and liners	Thin-wall aerospace components with knife edges
Gun tubes and sleeves	Radiant tubes for fired heaters, heat-resistant steel, as-cast condition	Tubing for reformers, heat resistant steel, as-cast outside
Heat exchanger tubes	Railroad car wheels and bearings	Turbine blades
Heavy-wall tube liners for extrusion machines	Rainwater pipes, cast iron, as-cast condition	Valve balls
Helium liquifiers	Reactor tubes and cylinders for atomic power	Valve bodies and housings
Hinges	Retorts	Welding rods
Hoist drums		

Table 1-3. Industries Using Centrifugal Castings

SIC Classification	Industry
13	Petroleum and natural gas production
22	Textile mill products
24	Lumber and wood products
26	Paper and allied products
28	Chemicals and allied products
29	Petroleum refining and related industries
32	Stone, clay and glass products
33	Primary metal industries
35	Machinery (except electrical)
3519	Internal combustion engines
3523	Farm machinery
3531	Construction machinery
3532	Mining machinery
3533	Oil field machinery
3535	Conveyors and conveying equipment
3536	Hoists and cranes
3537	Industrial trucks
3542	Machine tools
3544	Special dies and tools
3547	Rolling mill machinery
3549	Metalworking machinery
3551	Food products machinery
3561	Pumps and compressors
3562	Ball and roller bearings
3566	Gears
3567	Industrial furnaces and ovens
37	Transportation equipment
3711	Motor vehicles
3714	Motor vehicle parts
3720	Aircraft parts
3731	Ship building and repairing

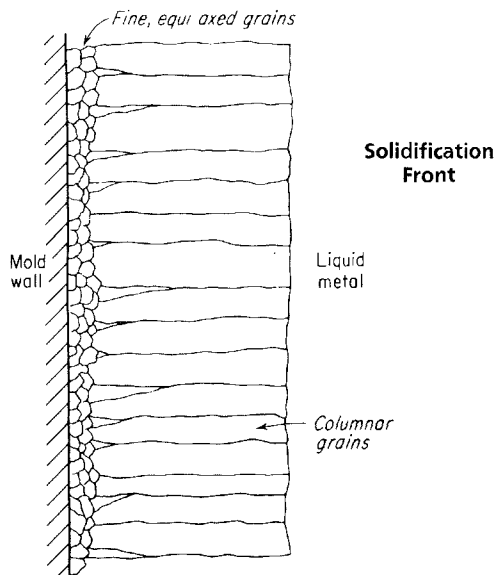
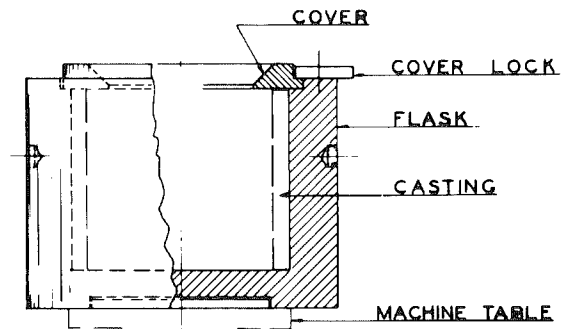
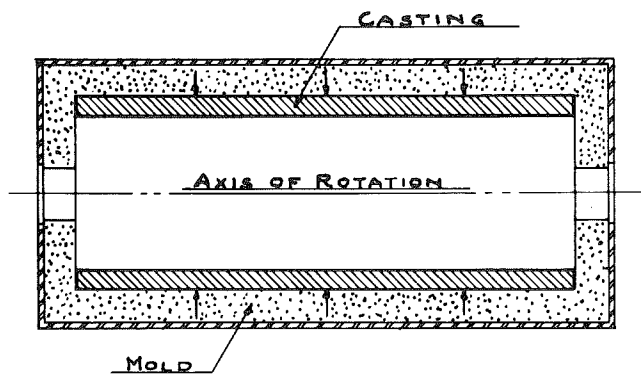


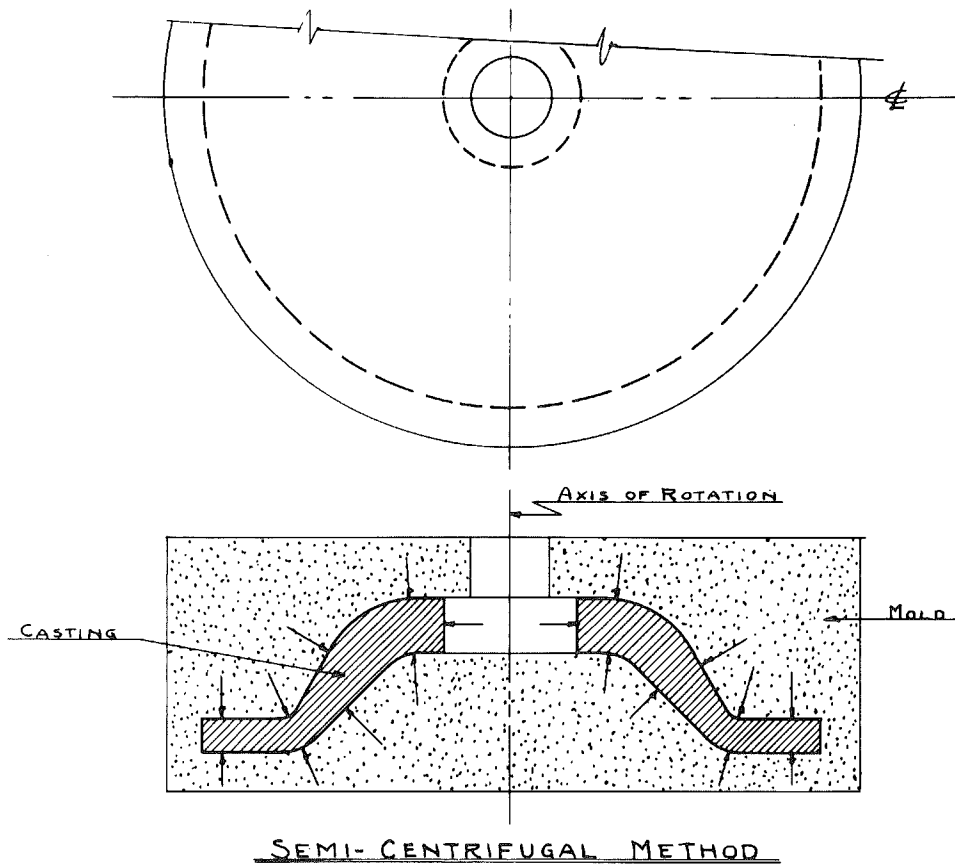
Fig. 1-4. Typical columnar grain growth.



METAL MOLD
FOR VERTICAL CASTING MACHINE

CYLINDRICAL CASTING
TRUE CENTRIFUGAL METHOD

Fig. 1-5. True centrifugal casting.



SEMI-CENTRIFUGAL METHOD

Fig. 1-6. Castings that are neither round nor cylindrical, but spun about their own axes, are termed "semi-centrifugal." Arrows show direction of cooling.

We call this type of casting "true centrifugal casting" (Fig. 1-5). Perfect directional solidification exists with little or no effort on the part of the operator. It is due to the conformation of the mold. True directional solidification usually exists in all cylindrical castings.

Method II—Semi-Centrifugal Casting

This is very similar to Method I; however, due to the irregular contour of the internal bore, it is necessary to use a core. Solidification occurs in both inward and outward directions, with the consequent problem of centerline soundness (Fig. 1-6). Feeding, however, is enhanced by centrifugal force and is equivalent to the use of very high risers [hydraulic heads of over 100 equivalent feet (30.48 m) of molten metal are possible]. Gates of various types may be used, some of which serve as a riser and others for the direction of metal into the mold cavity. Method II is adaptable to a wide variety of cast parts such as jaw clutches, sheaves, gear blanks, casing heads, and flanges.

Centrifugal casting is also used for the production of another type of casting, one which has very thin metal sections. Such castings would be very difficult to pour statically, because the molten metal might solidify before completely filling the mold cavity. The molten metal would not run into the very thin casting sections; thus, the casting would not be complete. By using centrifugal force in pouring the metal into the spinning mold, the additional force added to the normal static pressure head causes the metal to flow into the thin or narrow casting sections (Fig. 1-7).

Method III—Centrifuge, or Pressure Casting

In this method (usually done vertically but sometimes horizontally), there is a central sprue at the axis of rotation of the mold. Mold cavities are clustered about the central sprue in a symmetrical array, each connected to the sprue by one or more radial gates (Fig. 1-8). Since conditions are not designed to promote ideal directional solidification, it is necessary to apply skill and ingenuity in gating so as to promote solidification from remote points of the casting toward the gate (which also acts as the riser). Usually, only small castings such as unions, valve bodies, gates, plugs, and intricate parts are cast by this method.

Practical applications for the various types of centrifugal castings are illustrated by Table 1-2. Standard industrial classifications of industries using centrifugal castings are given in Table 1-3.

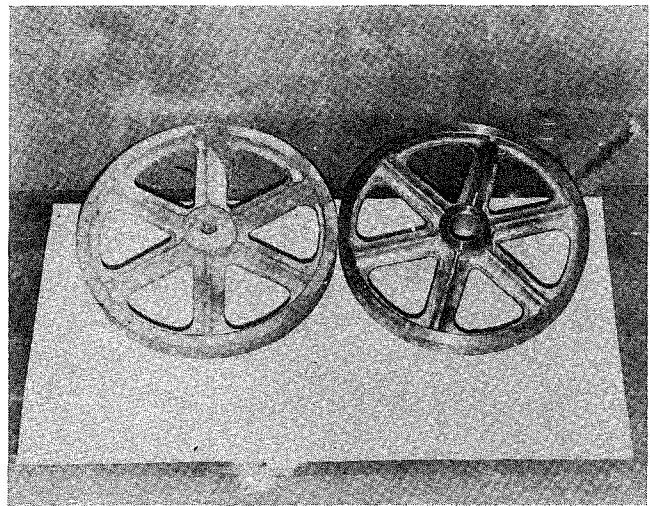


Fig. 1-7. Sheave casting.

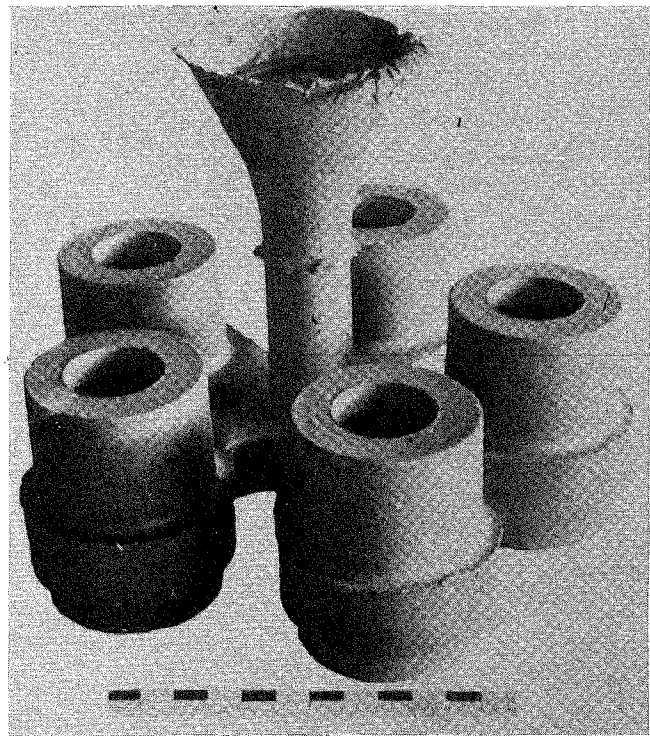


Fig. 1-8. Five castings centrifuged in one mold with irregularly-shaped cores. Note smooth surfaces.

Types of Machines

INTRODUCTION

There are various types of casting machines used to produce centrifugal castings: horizontal axis machines, vertical axis machines, and face-plate machines, to name a few.

True centrifugal castings may be produced in either vertical or horizontal axis casting machines. The general criteria for the decision as to whether or not castings should be produced in a vertical or a horizontal axis casting machine are summarized in the following paragraphs.

HORIZONTAL AXIS CASTING MACHINES

If we intend to make a true centrifugal casting, we assume that it is essentially a tube or cylinder with the bore concentric to the outside diameter. It is possible for the tube or cylinder to have various diameters on the outside, but it must have a uniform diameter on the inside (Fig. 2-1). In other words, the inside diameter of the tube must be a cylinder. As a rule of thumb, one ordinarily uses a vertical machine to make castings whose length is less than two times its inside diameter. If the length is more than two times the inside diameter, the casting is usually made in a horizontal machine.

In the case of horizontal trunnion machines (Fig. 2-2), the mold itself rotates on the trunnions. If the mold is machined with the inside diameter of the mold concentric with the outside diameter of the mold, the castings produced will always be absolutely concentric with the mold. The wall section is the same throughout the circumference of the casting. It is usual to use horizontal machines to produce castings having a true cylinder as the inside diameter.

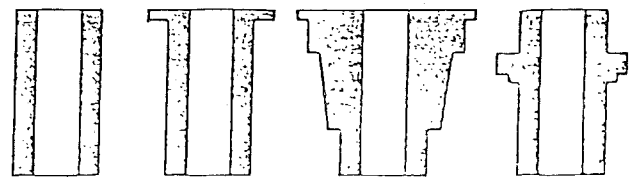
VERTICAL AXIS CASTING MACHINES

Vertical centrifugal casting machines are made in many different sizes, capable of handling loads up to at least 50 tons. Horizontal centrifugal machines are also capable of handling loads in this range or greater. There appears to be no limitation as to the weight or size of castings that can be produced centrifugally. The same basic criteria exist for small castings as for large castings. Accordingly, the vertical casting machines are made in several configurations. Some of them are mounted on the floor and are readily portable

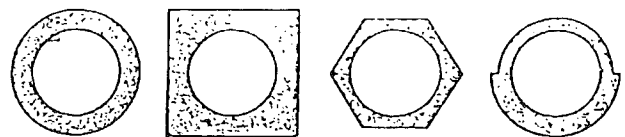
(Fig. 2-3), and others for producing heavier castings are mounted below floor level in heavy concrete foundations. Various types of guards are used about the machines to protect the workmen from the possibility of any flying molten metal.

Basically, a vertical casting machine is one having a spindle or shaft with a set of bearings, driven at one end by some type of motor, and having a face-plate or table at the other end (Fig. 2-4).

In the case of a true vertical centrifugal casting, there will be some vertical taper on the inside surface of the casting due to the earth's gravitational force. At the speeds normally used for the rotation of the mold, the amount of this taper is generally $\frac{1}{8}$ in. (3 mm) per foot. This small amount of taper is usually imperceptible unless the length of the casting is great. For this reason there is a practical limitation on the height of castings made in vertical machines. There is more information about taper in Chapter 8: Rotational Speeds.



Typical Axial Sections



Possible Cross Sections

Fig. 2-1. Plan and elevation views of typical "true centrifugal" casting sections.

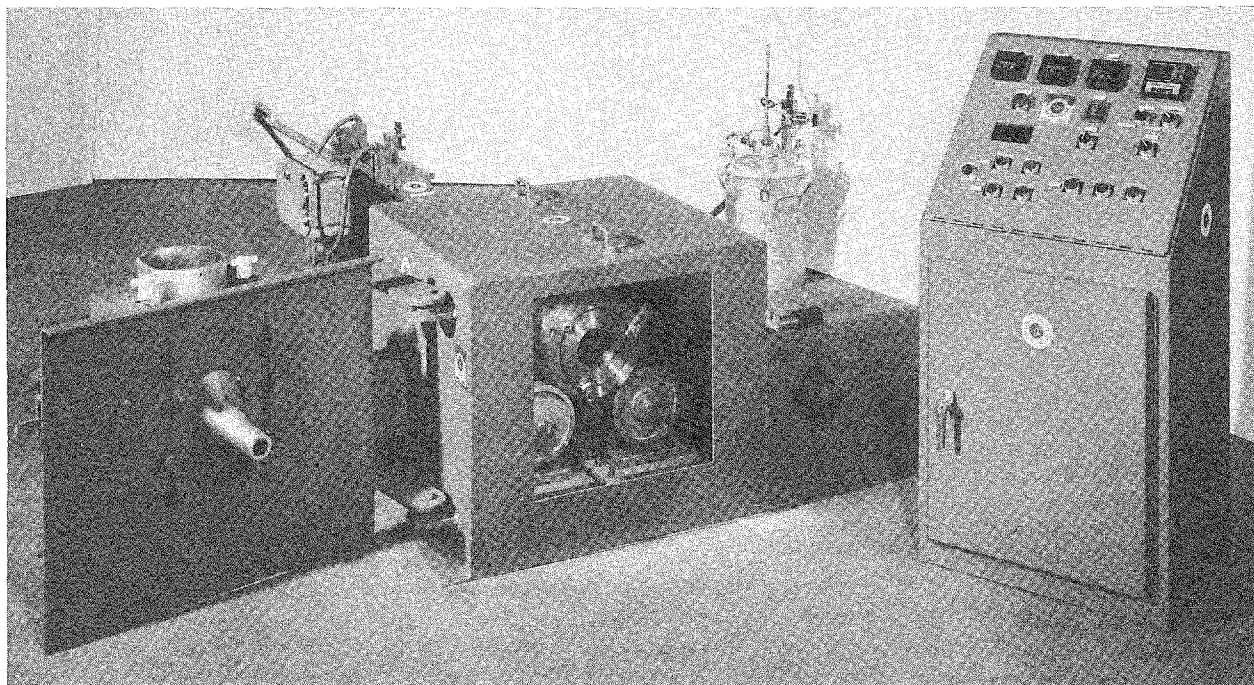


Fig. 2-2. Small horizontal trunnion machine with automatic "Rolance" mold spray and semi-automatic controls.

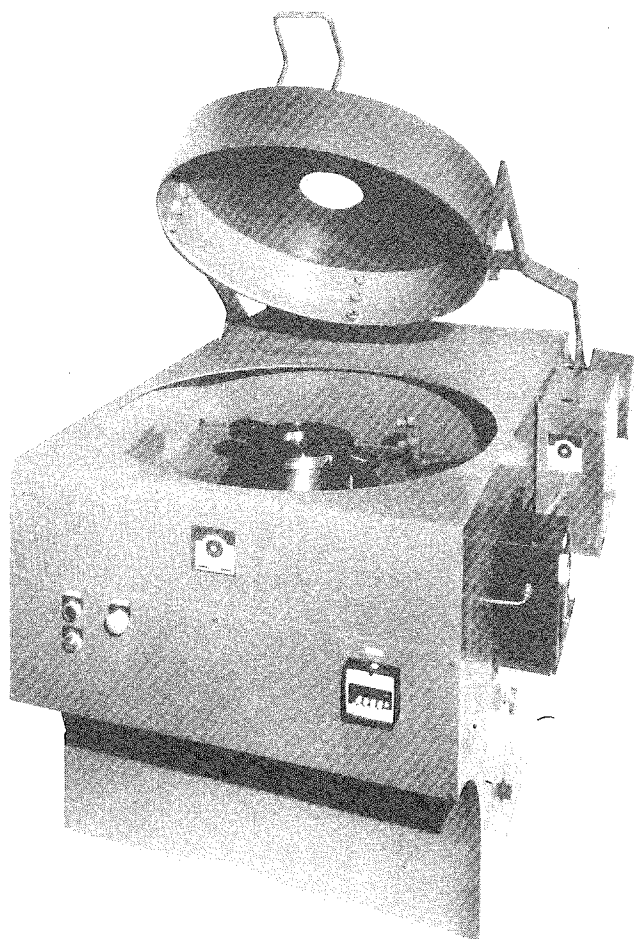
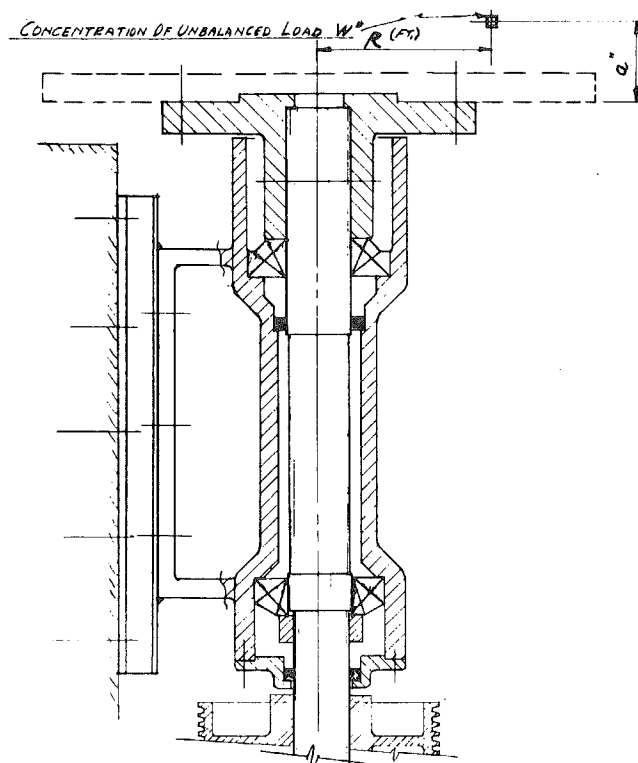


Fig. 2-3. Small vertical-axis casting machine, floor model.



BEARING CAPACITIES 500 HOURS AT 500 RPM.			
	RADIAL	THRUST	STATIC
MODEL "C"	23200	32200	104,000
MODELS "A" & "AS"	6840	8620	27860

Fig. 2-4. Vertical casting machine schematic.

FACE-PLATE CASTING MACHINES

A vertical casting machine, if placed with its axis of rotation horizontal, is then called a face-plate machine (Fig. 2-5). It is important that the machine be of proper design with proper thought given to the lubrication of the spindle bearings, as it is not possible to merely change the axis of a casting machine from vertical to horizontal and provide proper lubrication to the bearings. However, if this is kept in mind during the design stage, only minor changes are required in the lubrication system.

In certain types of machines, such as vertical or face-plate, it is necessary to attach the mold to the face-plate in such a manner that the inside diameter of the mold will be absolutely concentric with the axis of rotation. This requires very accurate fitting of the mold to the machine face-plate or table. It also creates problems with respect to the mold getting hot and therefore expanding—quite appreciably in the case of large diameter molds. There is the resultant possibility of misalignment, thus causing imbalance.

Face-plate type casting machines are used for producing short-length cylindrical castings or rings, whereas trunnion-type horizontal casting machines are generally used for producing long-length horizontal centrifugal castings, such as pipes and tubes.

In the cases of face-plate or vertical type machines, if the mold is offset from the center by even a small amount, the result will be that the casting will be thicker in wall section on one side than on the other. The inside diameter will always be concentric with the axis of rotation. This only applies to true centrifugal casting.

INCLINED AXIS CASTING MACHINES

A few foundries utilize face-plate type casting machines that are mounted at a small angle from the vertical (15–30 degrees). These machines are usually used to produce nonferrous castings. The inclination facilitates the pouring of molten metal directly from a ladle (usually hand-held) (Fig. 2-6). A runner pot is not required and only small castings are poured; usually less than 50 lb in weight.

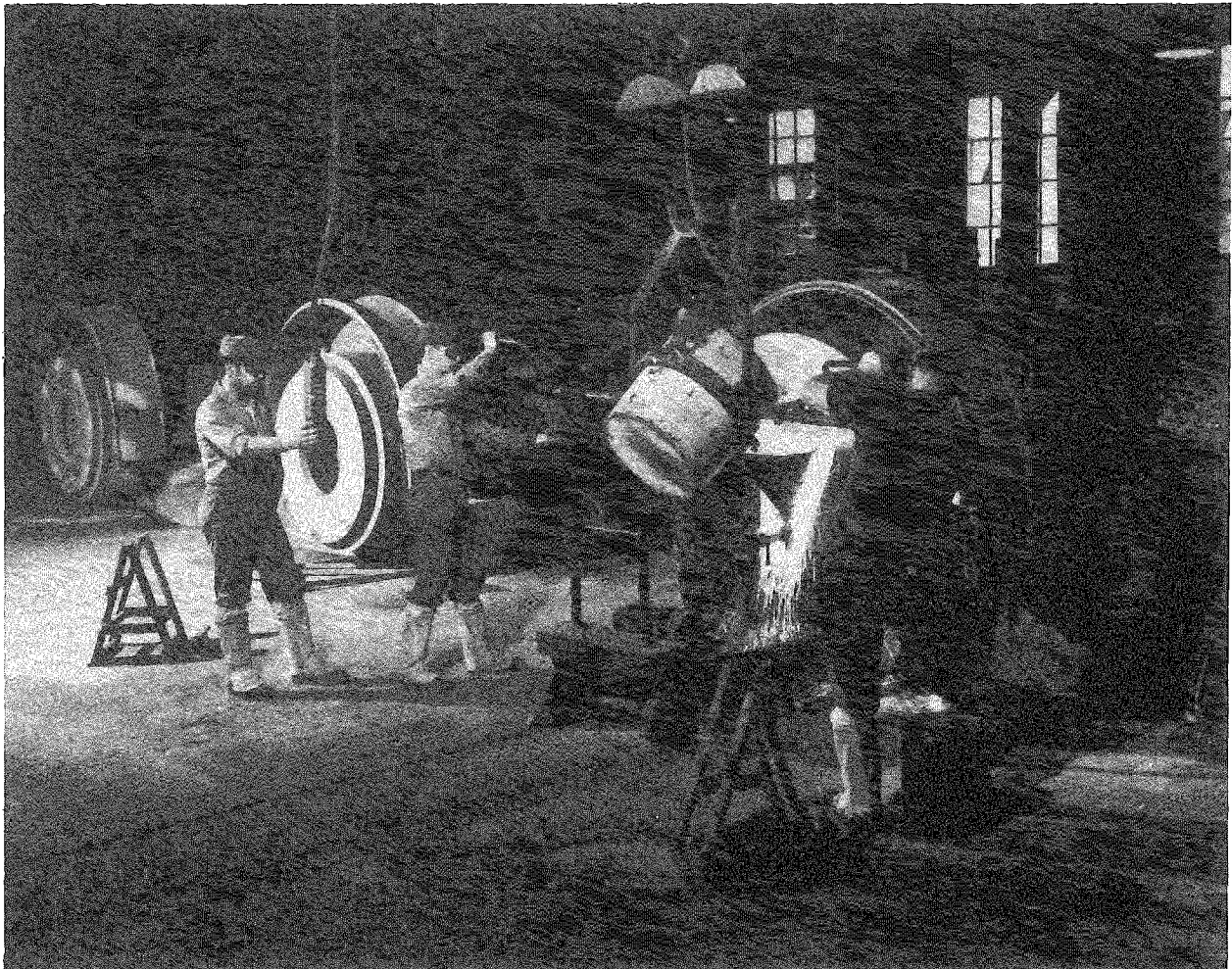


Fig. 2-5. Model "R" face-plate centrifugal casting machine for large-diameter, narrow-width castings; capacities up to 6000 lb.

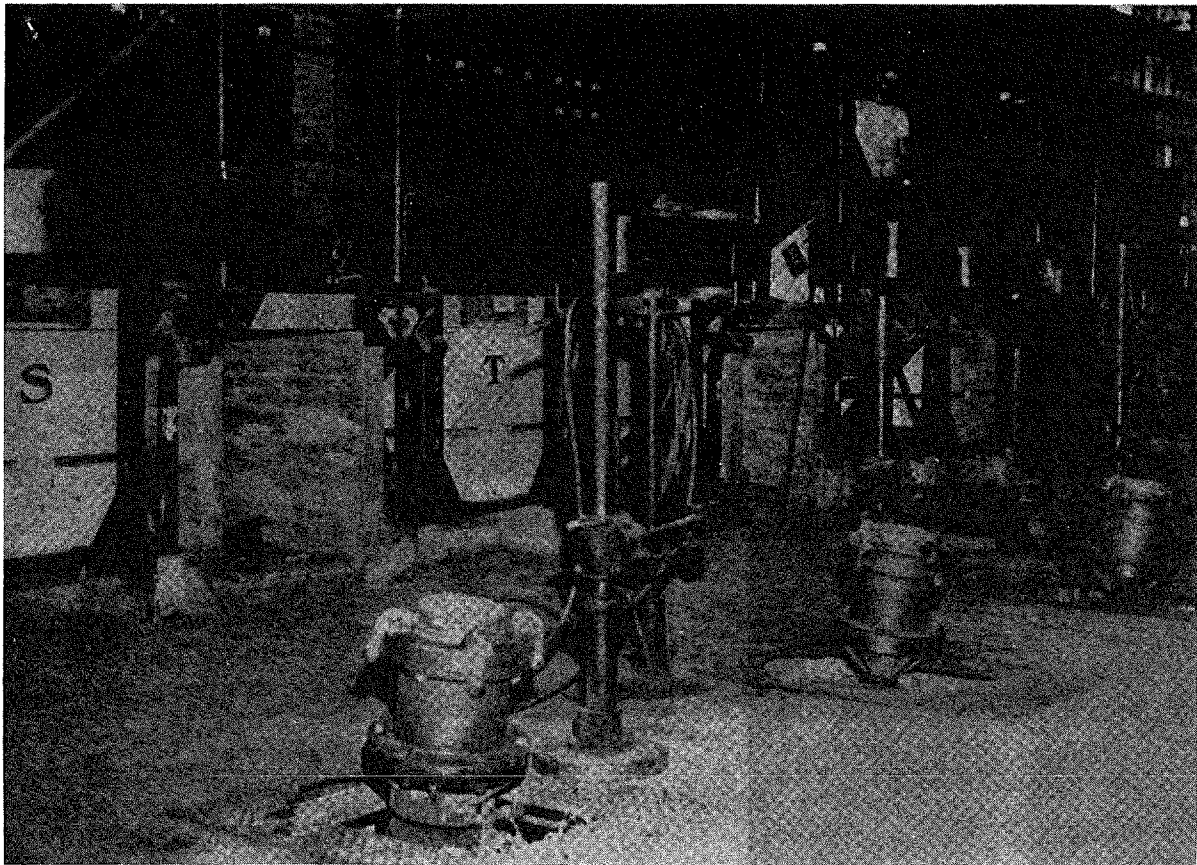


Fig. 2-6. Small, inclined-axis casting machines.

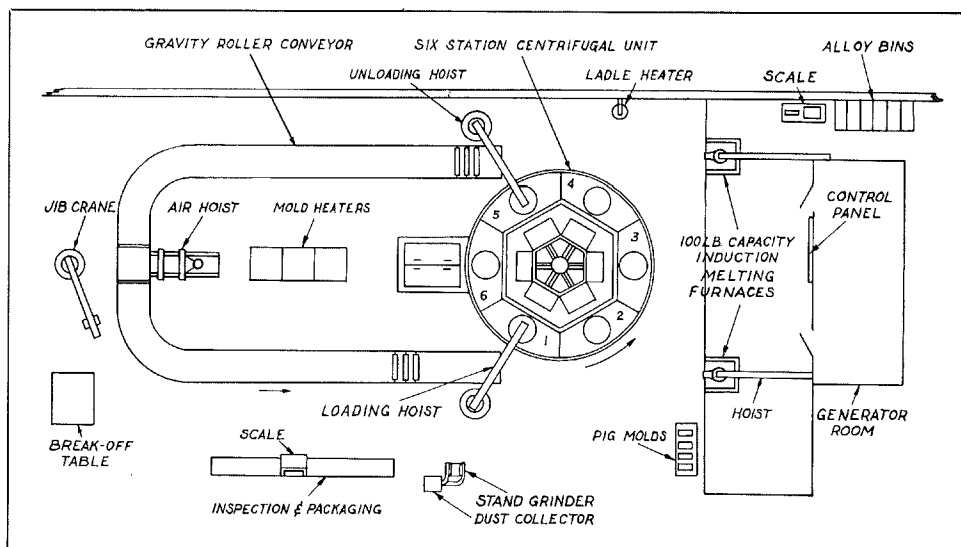


Fig. 2-7. Plan showing a turntable installation set-up.

ADDITIONAL VARIATIONS

Turntable Installations

The preceding text describes the fundamental types of centrifugal casting machines: vertical, horizontal, and face-plate. Machines of various sizes and types can be mounted on a turntable, wherein several casting machines of the same type are mounted on the periphery of a large table. The table rotates continuously, very slowly, or indexes from station to station, and permits much higher casting production than can be obtained from a single casting machine. The turntable casting machines have many advantages over the single station casting machines in that there is less handling of the molten metal and they are much more receptive to the application of automatic pouring and automatic casting removal. An illustration of this type of set-up is shown in Figure 2-7.

In deciding whether or not a turntable casting machine is suitable, it is necessary to know the production requirements for particular castings to be produced. After the metal is poured into a given mold on a turntable, the time involved before this mold comes back to the pouring position must be long enough so that the molten metal has had sufficient time to solidify and be removed from the mold.

Depending upon the wall section of the casting, which really determines its solidification time, a turntable might require anywhere from 4 to 12 casting machines. Thus, the number of casting machines required on a turntable is determined by the solidification time of the particular castings being produced.

For an indexing type turntable, the time of dwell at a particular station is adjustable and the overall time for a mold to make the complete rotation back to the pouring station can be precalculated, as in the following example:

$$st = d - p + (cs \times d) + (cs \times t) + t + e$$

where

- st = solidification time of the casting *→ katlasma surest*
- d = dwell time at each station with 15-second minimum *→ Behtane jurest*
- p = pouring time *→ do line zamani*
- cs = number of cooling stations, 5 *→ sagutma istakpan*
- t = index time, station-to-station, 5 second typical
- e = time at extraction station before extraction

Unlike dwell time in diecasting (which is the time of solidification during which a shot is held), dwell time for a turntable casting machine is the longest time required at any one station, which determines the minimum dwell time. Casting extraction usually requires the longest time (i.e., 15 sec).

For instance, if a casting takes 120 seconds to solidify, the pouring time required is 8 seconds, and the time at the extraction station before extraction takes 8 seconds, what is the index dwell time?

$$120 = d - 8 + (5 \times d) + (5 \times 5) + 5 + 8$$

Answer: 15 seconds.

The production rate, therefore, is: $3600 / 15 + 5$ or 180 castings per hour.

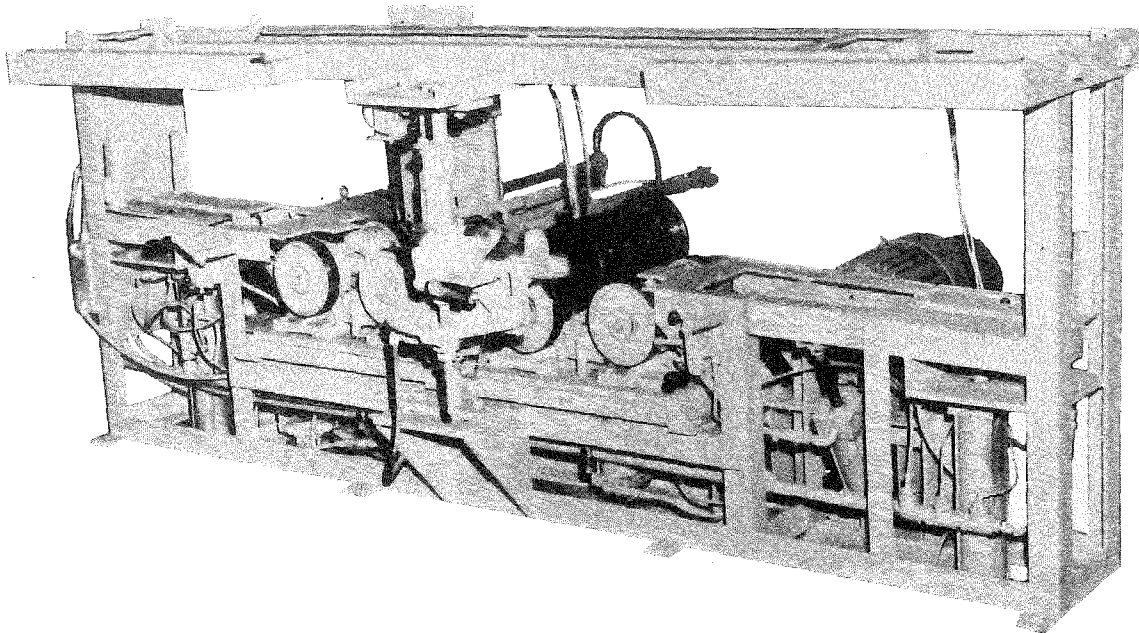


Fig. 2-8. Over-and-under casting machine for cylinder liners.

The larger diameter, heavier-wall castings require a longer time for solidification, more time for performing the various operational steps and, therefore, have a proportionately lower production rate.

Turntables vary in diameter from 8 to 22 ft (2.4 to 6.7 m) with anywhere from 4 to 12 casting machines. Molds are sprayed at one station, while the pouring operator remains in position and pours into each machine as the turntable indexes around. The castings cool as they move through various other stations, arriving finally at a station where the castings are ejected or removed from the machines. Each mold is then prepared and the metal poured for the next casting.

Over-and-Under Machines

Another high-production centrifugal casting machine is the over-and-under type (Figs. 2-8 and 2-9); it uses one or more horizontal trunnion type casting machines (i.e., one for casting and one for mold preparation), and the molds are transferred from one station to another. These very successful casting machines are used for the production of cast iron pipe or other cylindrical castings, such as cylinder sleeves, with production rates of up to 150 castings per hour. The

advantage of this type of casting machine is that a large number of castings can be produced per hour by a relatively small manpower input; usually two or three people are required for the entire casting operation.

A disadvantage of this type of casting machine is that, if it is the only casting machine in the foundry producing a particular type of casting, the slightest defect in a limit switch or other device will cause a complete shutdown of production. Thus, the production rate will go from 100% to zero!

To evaluate the overall efficiency of a high-production casting machine, one should consider downtime due to component failure or projected life and, thus, the production that will be obtained per month, rather than per hour, should be used in evaluations. It may be more efficient to use several single-station casting machines than one high-production casting machine. For instance, if the same limit switch becomes defective on an individual machine and there are, say, six machines, production is reduced by only one-sixth. In a high-production over-and-under or turntable machine, production would go to zero. This very important fact is often overlooked in evaluating the productivity of this type of casting machine.

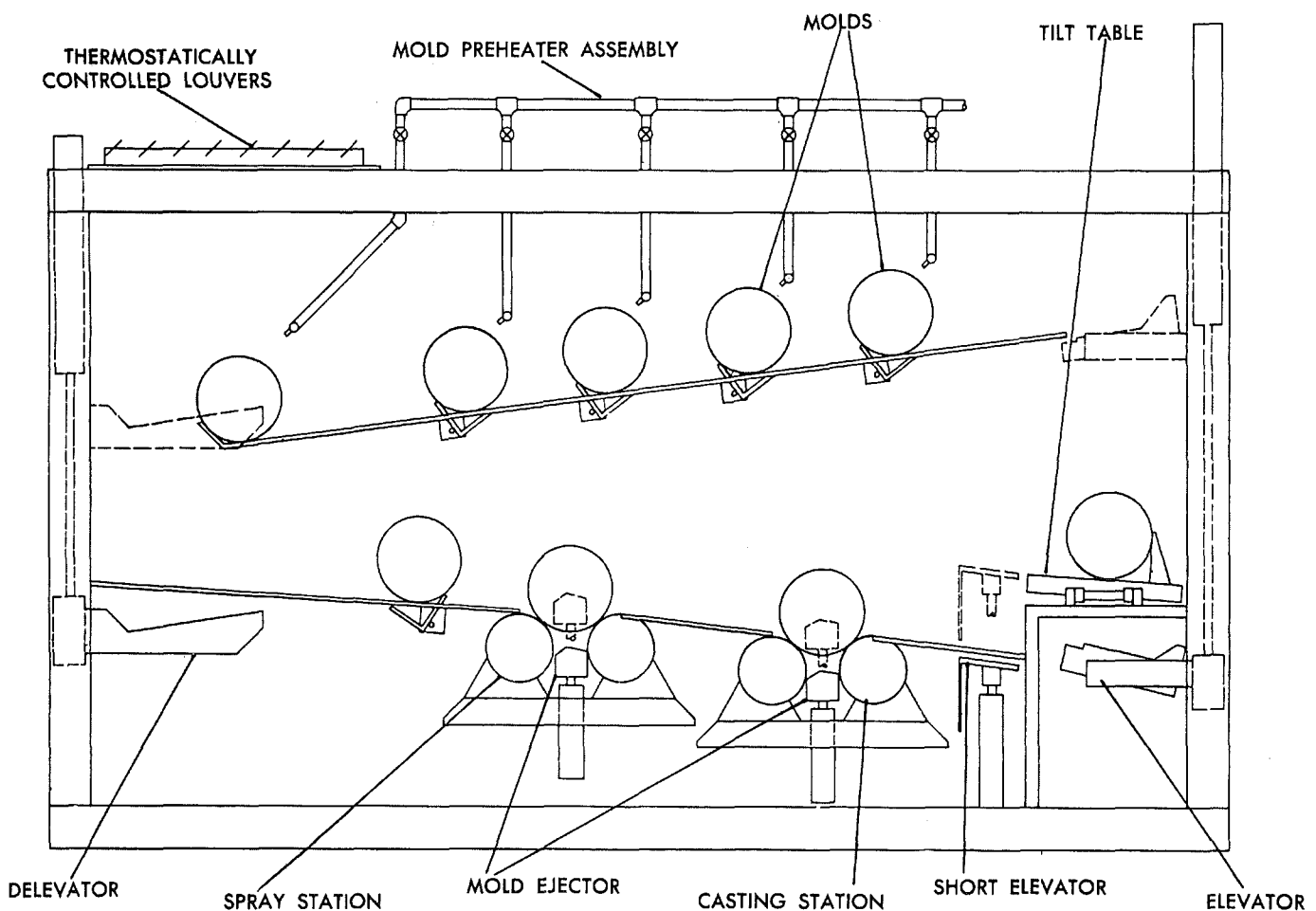


Fig. 2-9. A schematic of the over-and-under machine operation.

Ferris Wheel

Another high-production centrifugal casting machine is the Ferris wheel, which is actually an ordinary turntable machine with a horizontal axis instead of vertical (Fig. 2-10). This machine has been designed to eliminate the requirement for removal and reapplication of the end plate on the mold, for complete casting automation.

Vertical Roll Machines

Large bi-metallic steel mill rolls can also be cast in large heavy-duty vertical centrifugal casting machines (Fig. 2-11). In this process the mold body and two necks are assembled and attached together to form a vertical mold. The assembly is lowered into a pit (below floor level) onto the table of the vertical centrifugal casting machine. Trunnions located part of the way up from the bottom (lower end) of the assembled mold hold the mold in a vertical position. The hard iron for the outer shell of the roll body is poured through a spout that extends through the upper neck. The shell is cast at a relatively high rotative speed, then stopped or rotated slowly while the soft iron is poured directly into the mold through some sort of controlled flow tundish, until it fills the mold cavity completely. This process is very similar to that used to produce rolls in a horizontal casting machine except that no mold transfer is required. The cost of a vertical roll machine is very much greater than the cost of a horizon-

tal centrifugal casting machine for rollmaking, and the quality of the cast bi-metallic roll has been a subject of lengthy debate with regard to vertical versus horizontal spinning axis. (More about roll machines in Chapter 14: Metallurgical Aspects.)

Babbitting Machines

Babbitt lining machines are used to line bearings with babbitt or white metal in sizes from 2 in. (50.8 mm) in diameter up to 6 ft (1.8 m). (See Chapter 11: Specialized Castings.)

This type of centrifugal casting machine (Fig. 2-12) usually spins a babbitt lined-type bearing shell on a horizontal axis between two face-plates, one of which is clamped tight against the other to hold the spinning bearing shell centered about the spinning axis and to prevent the leakage of molten babbitt from the ends of the bearing shell. The molten babbitt metal is poured through a pouring funnel that protrudes into the bearing shell through a hollow spindle in one of the face-plates.

Vacuum Machines

When casting some of the more exotic and reactive metals, such as uranium and titanium, it is necessary that they be poured in a vacuum atmosphere. This can be accomplished in a variety of ways.

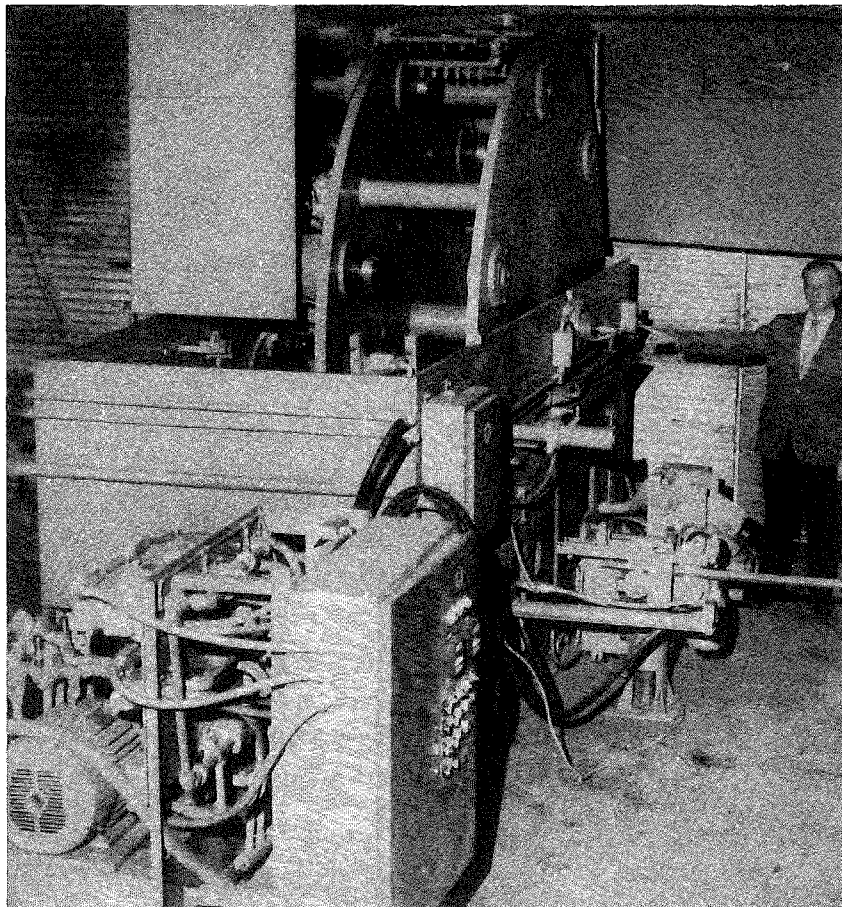


Fig. 2-10. Ferris wheel casting machine; fully automatic.

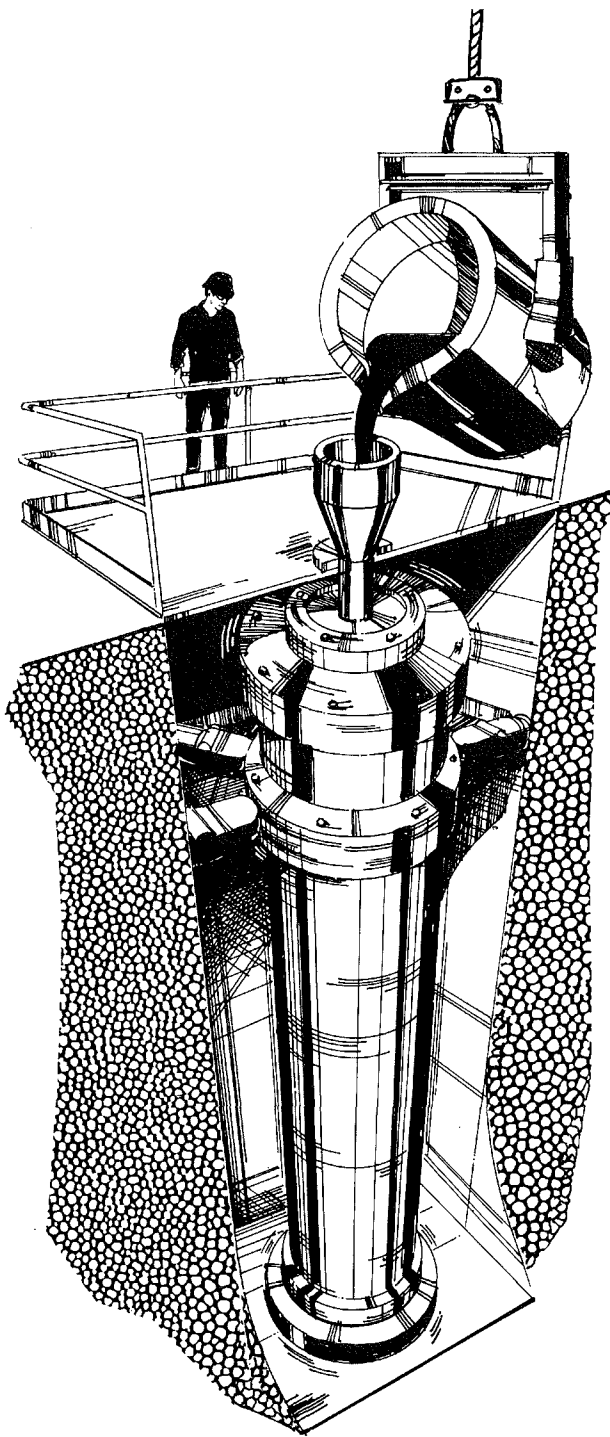


Fig. 2-11. Vertical roll casting machine.

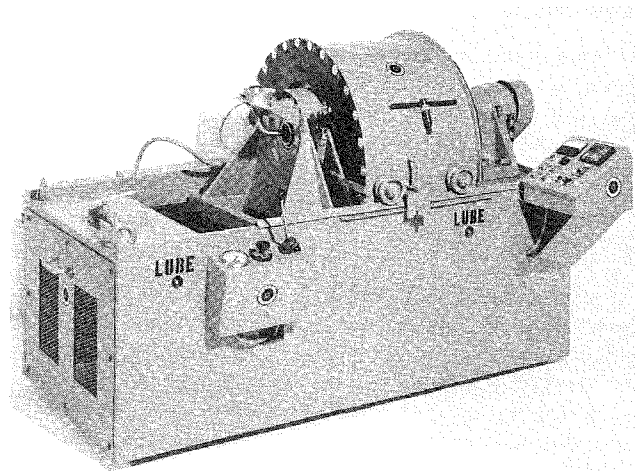


Fig. 2-12. Centrifugal babbitting machine.

When a vertical axis or horizontal axis face-plate type of casting machine is called for in the production of this type of casting, the machine proper can be located outside of the vacuum casting chamber with the machine shaft extending through the chamber wall into the vacuum. In this case a very suitable vacuum seal is required around the shaft, which projects into the vacuum chamber. Special designs of such rotary vacuum seals have been built and have proven themselves to be quite satisfactory with low maintenance and extremely low leakage of air into the vacuum chamber.

In other cases the entire casting machine is placed in the vacuum. Since the vacuum provides no method of cooling electric motors, it is usual to drive these machines hydraulically. Electrical devices, or in fact any other devices, are never 100% efficient, and require some cooling for their satisfactory operation. In the case of electric motors, the cooling takes place by means of a fan that circulates the air past the windings of the motor and keeps it adequately cooled for satisfactory operation. In the most satisfactory design, the entire machine is placed in the vacuum and is driven by a hydraulic motor with the hydraulic fluid lines extending through the wall of the vacuum chamber to the hydraulic pump assembly.

While ordinary hydraulic fluids can be used, the grease or oil used for lubrication of the machine bearings must be carefully considered. They must be of very low vapor pressure so as not to be lost to the vacuum of the chamber.

Under normal circumstances no particular problems are encountered in utilizing centrifugal casting machines that cast metals in a vacuum. While permanent molds are generally used in this technique, graphite or carbon molds are also used to a considerable extent.

Installation Designs

INTRODUCTION

All centrifugal casting machines require a relatively heavy, firm foundation. It is highly desirable that the mold be perfectly dynamically balanced. However, as a practical matter, it is not possible to have a perfectly balanced mold on a machine. The casting machines are designed to accept a relatively large amount of imbalance in the molds and even in the casting. The machines are mounted on heavy bases, usually of steel or cast iron, and then on very heavy concrete foundations. Sometimes small vertical or horizontal machines are mounted on a structural steel base, which can then be bolted down so as to allow the machine to be moved from one place to another for experimental or varied work.

VERTICAL CASTING MACHINE INSTALLATION

Vertical centrifugal casting machines are generally mounted in a concrete pit with the table of the machine at floor level. In some cases, particularly with the large vertical machines, the table is located below floor level. When the table is located below floor level, the top of the mold will also be below the floor level (Fig. 3-1).

Guards

This configuration utilizes the pit itself as a guard for protection from flying molten metal, etc. However, for smaller machines it is more convenient for the table to be located at floor level so that molds can be easily placed on or removed from the machine. In this case, a guard surrounding the machine would be used during the pouring operation.

Various types of guards are available. Some raise themselves up and rotate so as to present an area of the machine table to the workmen for mold removal and replacement (Fig. 2-3). In other cases, a simple bail-type guard is used (Fig. 3-2) and is later removed by means of a crane or hoist.

HORIZONTAL CASTING MACHINE INSTALLATION

Horizontal centrifugal casting machines are usually mounted at floor level; sometimes slightly higher, sometimes slightly lower. The elevation above floor level is determined by the need for easy accessibility. The centerline of a machine should be elevated or lowered depending upon

the ease of pouring, attaching and removing end-plates, mold preparation, and casting removal. Pipe machines are generally located somewhat above floor level so that the center of rotation of the mold is at a convenient height for the operator to place the bell cores in one end of the mold. In most cases, a permanent mold has to be internally coated with mold coating. This can be performed more conveniently if the mold centerline is located above floor level (Fig. 3-3).

Guards

From a safety standpoint it is desirable for the machine to be enclosed to protect the workers, particularly during the pouring operation. It is possible for a run-out to occur from one or both ends of a spinning mold, which would cause a pinwheel of molten metal to be ejected from the end of the mold. A suitable guard is quite important.

The guards shown earlier in Figure 3-2 are made of steel. Some have a hinged top so that the molds can be readily removed and replaced. In other cases, the entire guard is lifted off the machine to replace the mold. For very small machines it is usually possible to remove the mold from under the guard without removing the guard from its normal position.

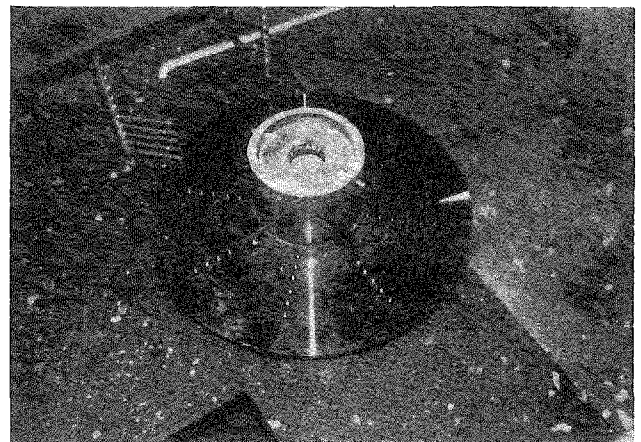


Fig. 3-1. Large vertical casting machine with the table below floor level.

In the case of very heavy machines it is convenient to use a concrete wall type of guard (Fig. 3-4), whereby the machine is merely placed between two heavy concrete walls equipped with a steel cover. The cover rides on tracks and can be moved longitudinally out of the way so that the molds can be easily accessed. At the pouring end of the machine, a "car" is used upon which the runner pot is located. This car incorporates a guard to protect the workmen during the pouring operation in case of a run-out.

CASTING MACHINE DRIVE SYSTEMS

Determining Motor Size

The actual horsepower required to drive a centrifugal casting machine is quite low, since the only load on the drive unit is windage of the rotating mold or mass in the machine, and the friction of the bearings. Because the bearing friction is generally very low, the principal load is actually the friction of the shaft seals. The load due to the shaft seals can be quite high. Because of this, the shaft seal design is quite important to maintain a relatively low friction factor to reduce the horsepower requirements, yet keep contaminants away from the bearings.

Although the actual running load is very low, it does not necessarily require a low horsepower drive. In practice, the inertia, or Wk^2 , of the mold and rotating components of the machine are calculated, then the desired RPM for the machine is determined; from this, the required horsepower is calculated.

$$HP = \frac{0.00000062 \times Wk^2 \times N^2}{T}$$

where

- W = weight in pounds
- k = radius of gyration (feet)
- N = revolutions per minute
- T = time in seconds
- HP = horsepower

The actual horsepower required for accelerating the load up to speed is principally determined by the length of time that is permissible for the load to attain speed. Usually, for most small centrifugal casting machines, the length of time that is permissible is something less than 30 seconds from standstill to spinning speed. For high-production machines,

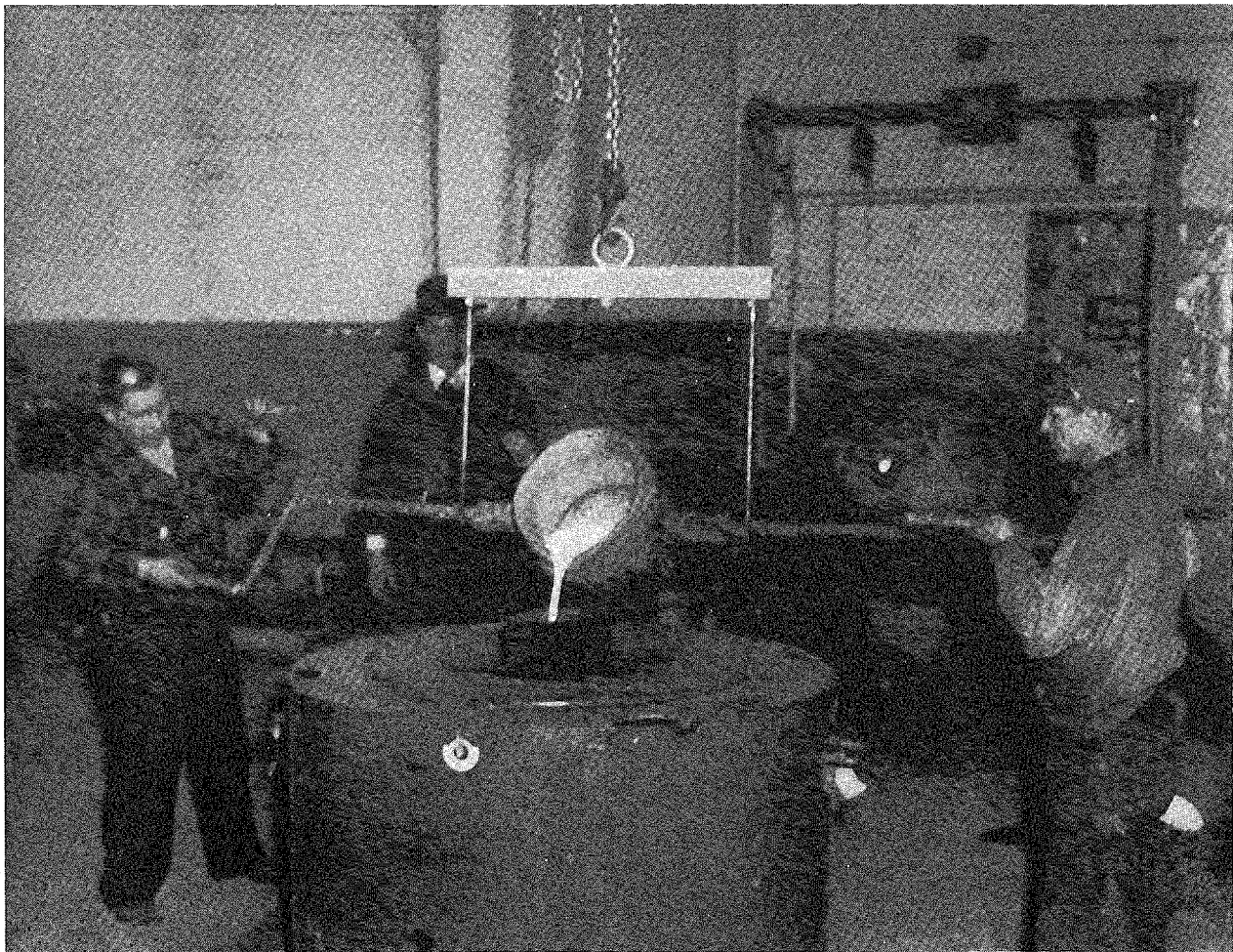


Fig. 3-2. Vertical casting machine with table at floor level and bail-type guard.

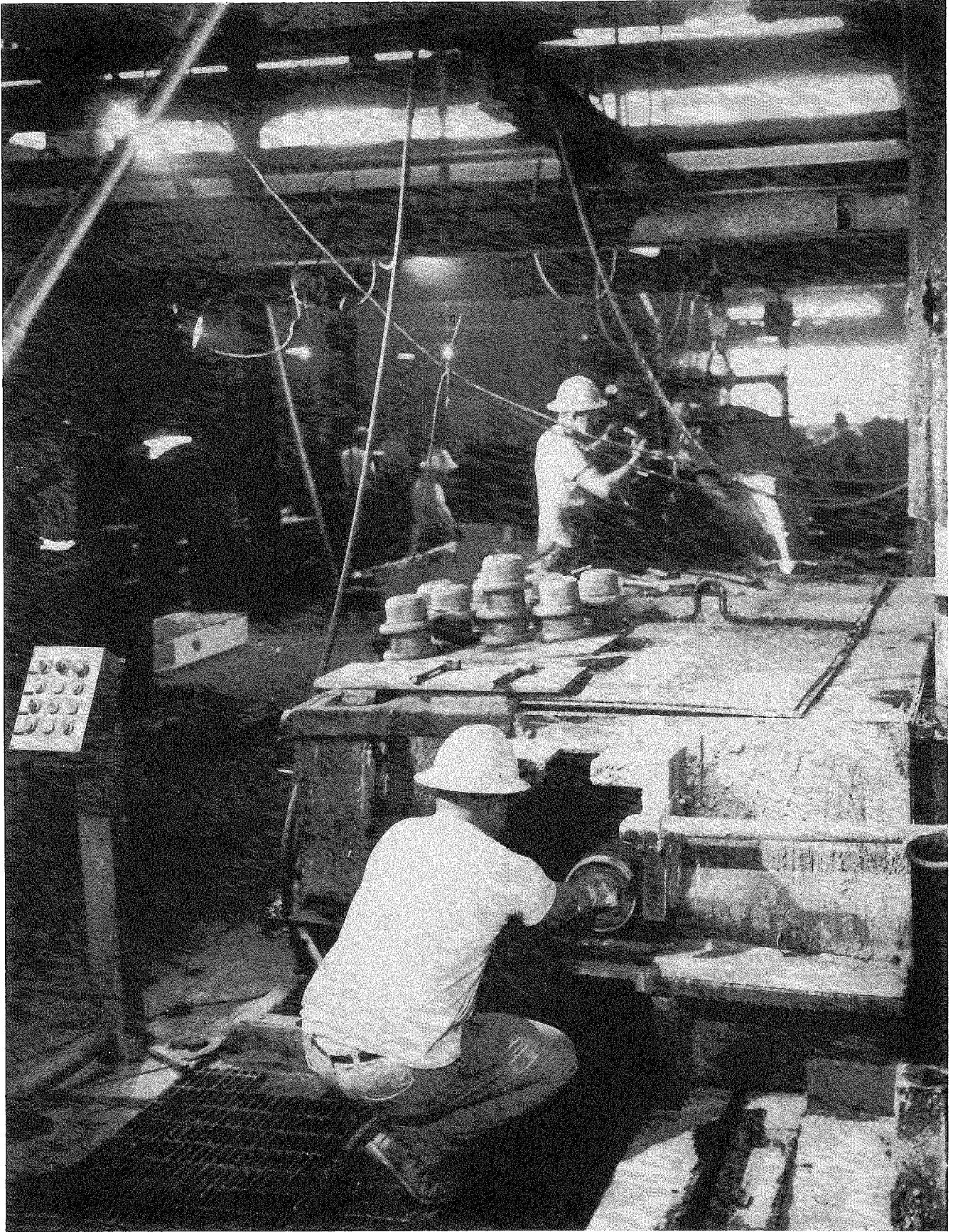


Fig. 3-3. Semi-automatic horizontal pipe casting machine mounted above floor level.

such as pipemaking machines, it is usually desirable to have the acceleration times and the deceleration times at 5 seconds or less. In the case of larger machines, used for the production of steel mill rolls, etc., much longer acceleration times can be utilized. In general, such acceleration times will run from 2 to 3 minutes.

Therefore, it must be realized that the determination of the size of the drive unit for a centrifugal casting machine is principally calculated from the Wk^2 of the load (including friction), the required speed, and the characteristics of the drive. Drive manufacturers provide information concerning the number of accelerations up to speed per hour or per minute that a particular drive system is capable of.

Choosing Drive Type

Electric Motors (AC & DC)

In the case of an ordinary AC induction motor, it is necessary that the size of the motor be adequate to bring the load up to speed quickly so as not to burn up the motor. Also, if the motor is far too small, the load on the motor could cause it to exceed the pullout torque, in which case the motor will never come up to speed and will burn up. This situation very seldom occurs, as it would evidence a *very* poor selection of drive size.

The scientific method of calculating the size of the drive motor, while fairly accurate, cannot be relied upon exclusively. The knowledge of an experienced engineer is required. This is because the same inertia and the same load are not used 100% of the time. In many cases the same machine must operate at higher speeds with lower inertia or at lower speeds with higher inertia. Also, rates of production vary widely. Therefore, an experienced engineer is most valuable in the selection of the drive. In many cases, the horsepower of a properly selected drive will be more than twice the horsepower normally considered to be required.

DC motor drives are quite satisfactory, but are expensive and are really not too suitable for repetitive accelerations. When such drives are used, a blower that runs continuously should be mounted on the motor. Thus, the motor will be cooled adequately, even at low speeds and during periods when the motor is not running.

Eddy Current Drive

The eddy current type of drive is satisfactory for use on centrifugal casting machines. In this drive the induction AC electric motor runs continuously. The output shaft only runs when energized by the eddy current clutch. The electric motor and clutch are continuously cooled by the blower (an integral part of the unit), whether or not the output shaft is rotating.

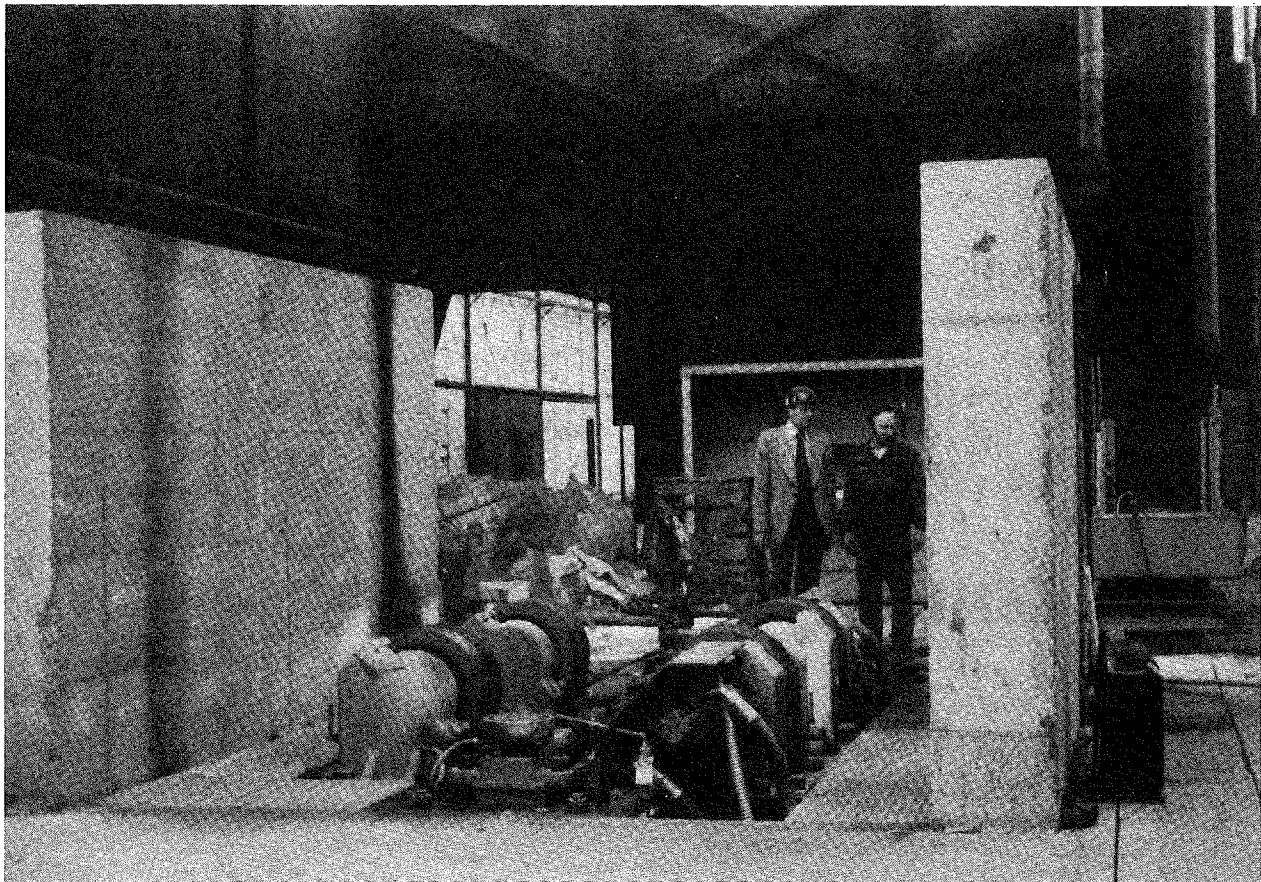


Fig. 3-4. Large horizontal trunnion machine with concrete wall guards.

The efficiency of such a drive at lower speeds is not very great. However, we must keep in mind that efficiency is unimportant, since we are principally concerned with accelerations. This type of drive, when electronically controlled, will permit the machine to come up to speed very quickly under controlled loads on the motor of from 150% to as much as 200% of full load current. By controlling the maximum current that the motor can draw, we eliminate the problem of the entire drive unit shutting down during an acceleration period when hot metal is available for pouring.

This type of unit is also very satisfactory for repetitively producing castings during periods of high production. The drive unit exerts very low horsepower when running, but can put out very large amounts of torque for acceleration. The fan that runs continuously provides cooling during all periods of the casting cycle, including the time when the output shaft is not rotating. Experience has shown that the air-cooled version of this type drive is most satisfactory.

Water-cooled versions of the eddy current drive are available, but are not recommended. When this cooling alternative is used, it is found that the water normally available will cause a buildup of calcium carbonate in the water cooling system of the motor. The result is that the motor finally builds up a chemical deposit internally and must be shut down for cleaning. In the case where a closed system is used, utilizing distilled water, the cost is very high and it requires excessive maintenance.

In the case of the eddy current drive, an eddy current type of brake is also available that can be integral with the drive itself. This is very satisfactory since it is cooled by the same air flow that cools the motor and clutch. The use of friction brakes of the ordinary designs are quite satisfactory and are widely used with all types of drives.

V-Belt Drives

Various types of v-belt drives and variable speed v-belt drives are used quite satisfactorily. The calculation of the size of drive unit is similar to that for an ordinary AC induction motor, since the drive is an ordinary AC induction motor. However, the inertia of the v-belt reduction system is quite appreciable and must be taken into account. When such a drive is used, the horsepower requirement is appreciably increased because of the drive itself. When a brake is used, it should be mounted on the output shaft of the drive so that the braking does not take place through the internal v-belt.

Hydraulic Drives

Hydraulic drives for centrifugal casting machines are very practical. When sizing hydraulic drives it is important to remember that acceleration is the important characteristic and not the load requirements. Thus, it is possible to considerably overload (up to 175%) the electric motor that is driving the hydraulic pump during the acceleration period. This results in a hydraulic system capable of a very high

horsepower, but driven by a relatively small horsepower electric motor. This is not readily understood by most hydraulic application engineers.

It is important that the control system for the hydraulic drive be such that when the system is told to "GO," it does so gradually. Most hydraulic valves will permit the hydraulic system to go from zero pressure to maximum pressure immediately. The result is that unsatisfactory things happen. Keyways in the drive system become wallowed out because of the rapid, abrupt accelerations and decelerations. On a machine with trunnion wheels, the initiation of the start can cause the trunnion wheels to slip on the mold itself for an appreciable time until the mold gets up to speed. Thus, a more controlled rate of acceleration must be designed into a hydraulic system.

Hydraulic systems have an inherent advantage inasmuch as controlled braking can be performed. In most cases, the energy consumed in the braking system goes into heating the oil. Thus, a larger heat exchanger for the hydraulic fluid is always required.

The hydraulic fluid should be a very high grade of hydraulic oil. When the drive is in a foundry adjacent to molten metal, it is always recommended that a non-flammable or fire-resistant fluid be used. When a non-flammable fluid is used, the hydraulic equipment, when purchased, should have compatible seals specified. Even though these types of hydraulic oils are considerably more expensive than other types of fluids, they do have lubrication characteristics that others lack. One should remember that the best synthetic or non-flammable fluid does not have as good a lubrication characteristic as a high-grade hydraulic oil.

Hydro-Static Drives

Hydro-static drive systems are most satisfactory and are now available with suitable controls to enable automatic accelerations up to speed, without overload of the system or overload of the electric drive motor. These hydro-static drives are generally used for the larger casting machines. They have an additional advantage inasmuch as the heat dissipated during deceleration does not necessarily go into heating up the hydraulic fluid, but serves to drive the electric induction motor, which then acts as a generator. The power is fed back into the electrical system rather than being dissipated as heat. The savings in energy is not particularly notable, but the fact that the hydraulic oil is neither heated up nor caused to deteriorate is of great importance.

Even though hydro-static drives operate at pressures up to as much as 5,000 psi (340 atm), they are very reliable and the associated equipment, such as hoses and fittings, is equally reliable. For all hydraulic systems it is recommended that all hoses be armored to protect them from molten metal splashes.

Lubrication

If the bearings in a centrifugal casting machine are oil lubricated, no special type of oil is required. However, care must be taken in the actual design of the machine's bearing

assemblies to see that the oil does circulate through the bearing, and that it does provide oil to the bearing surfaces, continually.

An air/mist system for the lubrication of bearings is very satisfactory indeed, and will permit the bearings to operate at a higher rotative speed than would otherwise be permissible. The air/mist system will not only lubricate the bearings satisfactorily, but will also provide some additional cooling. When such a system is used, it is important that the air being used is very carefully dried and that excellent filters and dehumidifiers be used for the air that goes into the air/mist system.

Most bearings in centrifugal casting machines are lubricated with grease. Only special kinds of greases can be used. Ordinary greases composed of an oil and a soap will not be satisfactory. The reason for this is that the bearing housings are relatively close to the hot mold. The hot ambient temperature will cause the grease to melt. The grease will then separate into soap and oil, and in a short while there will be no lubrication. The oil will settle out and possibly leak from the housing and will leave only soap, which is not a lubricant. It is therefore important that a type of grease be used that will not separate the oil and the soap. Greases that will satisfy this requirement are lithium-base greases, which are very widely available.

Molds

MOLD TYPES

Two categories of molds are used in centrifugal casting: expendable molds and permanent molds. Each will be considered in more detail below.

Expendable Molds

The expendable molds are usually made of sand, ceramic, or plaster. With such materials, it is necessary to completely destroy the mold to remove the casting. The methods for producing such molds for centrifugal casting are very similar to those used in ordinary static sand casting or in the "lost wax process."

In centrifugal casting, expendable molds find only limited use. They are primarily used when only one casting is to be made, when a very slow rate of cooling is required for metallurgical reasons, or because the casting is so large that a permanent mold would not be economically justified. This type of molding method is quite popular for the production of large, tubular products, such as stern tube bearings and ship shaft liners. The method of molding such castings is shown in Figures 4-1 and 4-2.

It is preferable to make castings in permanent molds, if possible. This is because the cost of making sand-lined (expendable) molds is such that high production is not economically justifiable. Furthermore, a comparison of the quality of the product produced in a sand-lined mold versus a permanent mold shows that the permanent mold, due to its more rapid chilling effect on the molten metal, will produce a casting with appreciably higher quality physical properties. The degree of enhancement of physical properties depends upon the metal being cast, and is usually greatest in the case of nonferrous metals.

Because of the difficulty encountered in producing absolute cleanliness in sand-lined molds, it is not unusual to find that some of the sand lining has broken loose and become lodged in the casting. This can be the result of poor molding practices, as well as erosion of the mold surface during the pouring operation. Therefore, centrifugal castings produced in sand-lined molds are generally inferior in quality to those produced in permanent molds.

Flasks

Current centrifugal practice is to produce everything possible in a permanent mold of one type or another. However, there are specialized cases where the use of permanent molds is not feasible. These include design configurations where the casting cannot be extracted from a permanent mold due to back drafts or protuberances, or simply where production requirements are very small. Accordingly, it would not be economical or possible to produce the casting in a permanent mold. In such cases, sand-lined molds are used.

In the case of sand molds, various types of flasks can be used to accommodate the sand. Round flasks can be used, which are identical to those used in static castings, except for the addition of certain lugs for centering in vertical machines. The requirements for a centrifugal sand mold or flask are naturally more stringent with respect to concentricity than with static casting.

One type of flask utilizes mold sections of dry sand cores, which are inserted into a hinged flask. Figures 4-3 and 4-4 show another type of flask used for centrifugal casting in sand or sand core molds. There are no special requirements for the material used for sand cores. In most cases, it is desirable to have a wire embedded in the sand to reinforce it, compensating for any centrifugal force that will be exerted on the sand body during the spinning period. The material for the mold can be silicate- CO_2 sand, dry sand, chamotte, or any type of fairly strong ceramic mold material. No special requirements are necessary for these materials for use in centrifugal casting.

When sand is used for centrifugal casting, it is almost imperative that a suitable mold wash be applied to all surfaces that come into contact with the molten metal in order to reduce mold erosion. Excessive mold erosion does not usually occur because the speeds of rotation are generally rather low when producing centrifugal castings in sand.

Most of the difficulty in producing centrifugal castings in sand molds is the result of careless molding practice. Such molds often contain loose sand particles that have fallen into the mold cavity. This naturally results in a poor quality casting with sand inclusions. There is more difficulty encountered from this effect than from mold erosion.

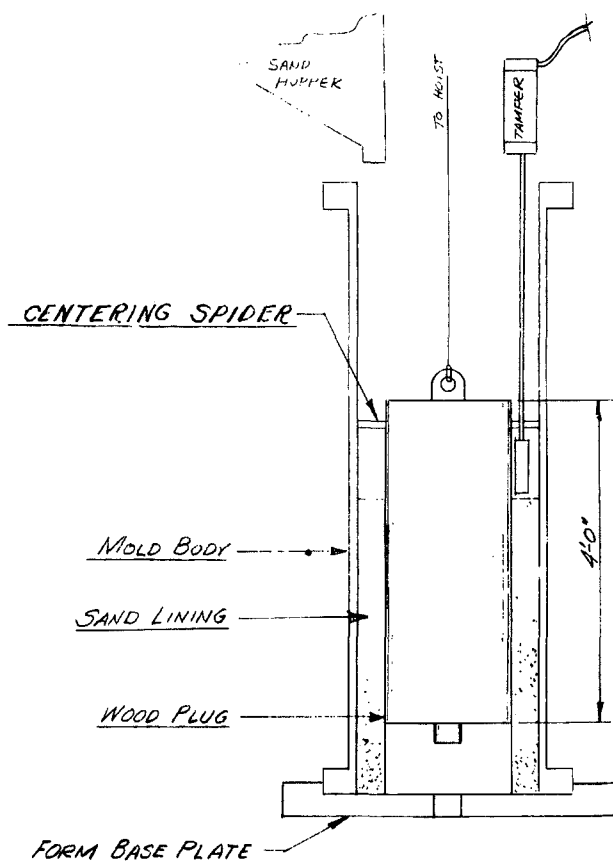


Fig. 4-1. Lining procedure for sand-lined mold: 1) select wood plug of proper diameter; 2) set up as shown; 3) pour sand into cavity and tamp until sand level is about 6 in. below top of plug; 4) raise plug approximately 1 ft; 5) repeat steps 3 and 4 until mold is filled; and 6) remove plug and sweep top of mold.

Flasks for Horizontal Machines: When making castings in lengths of more than 2 ft (609 mm) or larger than 10–12 in. (254–305 mm) in diameter, the flasks are generally rammed with green sand. The molds are first skin-dried with a mold wash applied to the inside before use. It is preferred that these molds be cast very soon after the drying process to prevent the moisture from the green sand being reabsorbed into the dry sand, causing defects in the casting.

When only a few castings are to be produced, the pattern cost should be minimized. In order to reduce cost, a very simple, short pattern is often made. The flask is located vertically with the pattern exactly centered. The sand is rammed into the annular space surrounding the pattern. The pattern is pulled up vertically in successive stages, while mold ramming is continued, until full height is reached. Thus, a mold can be produced with a very simple and inexpensive pattern (Fig. 4-1).

Flasks for Vertical Machines: In the case of vertical casting machines, the flask can be either rammed with sand while positioned on the bottom plate of the machine or it can be rammed up elsewhere and then transferred to the machine. The choice between the use of dry or green sand depends upon the size of the casting, the production requirements, and the casting configuration.

Various types of flasks can be used, such as those illustrated earlier in Figures 4-3 and 4-4. It is preferable that round flasks be used in order to achieve as balanced a mold as possible. When sand is used, it is necessary to use the lowest possible rotational speed for casting because the flasks will almost invariably have appreciable imbalance.

Permanent Molds

A permanent mold is one made of metal or graphite and can be used repeatedly for the production of many castings of the same form. Permanent molds are divided into two rough classifications. The first classification is molds made of graphite or carbon. The second classification is molds made of metal, such as steel, cast iron, or copper.

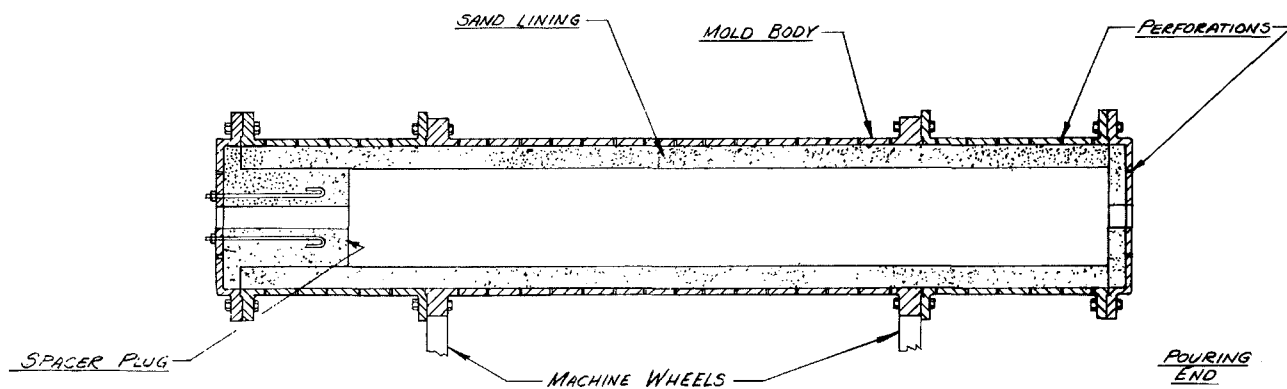


Fig. 4-2. Mold for ship shaft liners.

Table 4-1.
Comparisons Among Metal, Sand, Resin-Sand Molds, and Graphite

Item	Sand Mold	Metal Mold	Resin Mold	Graphite
Initial cost	Low	High	Low	Medium
Working efficiency	Allows use of the same metal casing or flask	Allows high repetitive production, up to 60 castings an hour	The same metal casting used 10 times or more per day	Good
Men	Many	Few	Few	Few
Flexibility of metal casting	High	None	Few	High
Life of metal casting	Long	2000–30,000 casts	Medium	5–100 casts long
Cooling rate	Low, no annealing required for cast iron	High	Medium, annealing required for cast iron	High
Application	Thick-walled pipe rolls	Suitable for any section	Suitable for thin-walled pipes	Short runs

Resin molds (shell molds) are made of thermo-setting plastic mixed with clean sand.

Graphite Molds

The choice between graphite or carbon molds depends upon the availability of graphite and carbon. Graphite has a higher rate of heat conductivity than carbon; thus, the choice is sometimes made because of the desired metallurgical properties for the finished product. In general, however, the choice is more clearly defined by the availability of scrap or odd lengths of electrodes from electric furnaces, the use of which results in a lower cost for the molds.

Graphite molds are usually quite expensive. However, since the graphite or carbon is readily machineable it is possible to very quickly machine-up a mold and be able to produce castings with a very short lead time, provided a stock of graphite is carried on hand.

The life of graphite molds may be as short as one casting. Usually the life will extend from 10 to 100 castings. Very seldom does one obtain any life appreciably more than a hundred castings. The material itself stands up quite well, but because it is soft, the mere process of removing the casting causes wear. If the operator is careless, he can break off a piece of the mold while removing the casting and thus completely destroy the mold for further use. Therefore, great care must be exercised in the actual removal of the castings from the mold.

Metal Molds

The more durable type of permanent mold is made of steel or cast iron. Some copper molds are in use for casting non-ferrous alloys only. While a great number of cast iron molds are used, there is a problem encountered in making them, because it is difficult to produce a cylindrical shape of high quality using the gravity casting method. Thus, in many cases, the molds for centrifugal casting are themselves produced by centrifugal casting.

Table 4-2.
Materials for Metal Molds

Material	Elements						
	C	Si	Mn	P	S	Cr	Mo
SAE 4130							
De Lavaud							
Rc 25–30	0.28–0.33	0.20–0.35	0.40–0.60	0.035	0.040	0.80–1.10	0.15–0.20
Common metal molds, including high-alloy steels							
SAE 1010	0.08–0.13		0.30–0.60				
SAE 1020	0.18–0.23		0.60–0.90			(particularly popular)	
SAE 1040	0.37–0.44		0.60–0.90				

For several reasons, it is not recommended that cast iron molds be used. One reason is because the savings in the material cost compared with those of steel are not very great, and another reason is that cast iron molds cannot be safely subjected to water cooling. It is found that a cast iron mold, when subjected to water cooling, will occasionally crack, rupture, or break. Steel molds do not ordinarily encounter this problem and, accordingly, are more commonly recommended. It is also felt that steel molds are more economical because of their longer life. (See Table 4-1.)

While many different alloys and types of cast iron have been used for permanent molds, ordinary gray iron, having a tensile strength of approximately 30,000 psi, has proven to be the most economical and the most satisfactory material. (See Table 4-2.)

If the production required from a mold is not very great, it will generally be found that use of an ordinary low-carbon steel, such as AISI E-1020, normalized and tempered at

1250F/677C after rough machining, will be very satisfactory. These molds, however, must be thoroughly stress-relieved during the manufacturing process. On the other hand, if a mold is to be used for pipe production, where it is used repetitively to produce castings, it is recommended that the mold be made of an alloy steel, such as AISI E-4130, fully heat treated.

Life of Permanent Molds

Although it is always of interest to have some idea as to what the life of a permanent mold may be, it is difficult to say that any particular mold will have a certain longevity. However, it has been found that a cast iron mold will, on the average, have a mold life ranging from 500 to 1000 castings. A steel mold, when used for the production of relatively small castings, such as cast iron cylinder liners and similar castings, will generally have a life of from 1000 to 3000 castings, usually in the higher range. An alloy steel mold used for the production of pipe will have an average life of from 2000 to 30,000 castings. Records are available for these types of molds that had lives of up to 50,000 castings.

Some companies have experimented with the use of a molybdenum lining in a permanent mold for both horizontal and vertical centrifugal casting machines. It has been claimed that the molybdenum lining considerably increases the mold life over that of a steel mold used without the molybdenum lining. The molybdenum linings that have been used were approximately $\frac{1}{4}$ in. (6.35 mm) thick. However, no comparative tests have been run to determine the difference in the life of a molybdenum lining without wash and a steel permanent mold with a refractory insulating coating.



Fig. 4-3. Molds made of dry sand cores being inserted into a hinged door type of flask on a vertical machine in a steel foundry.

Some of the above mentioned longer mold lives are due to proper maintenance of the mold, smoothing of rough spots that might be encountered, and occasional re-welding of an erosion defect that might develop.

Molds generally fail by thermal fatigue (heat-cracking). As the mold is used, the heat causes the inside diameter of the mold to attempt to get larger due to expansion. It then cools down when the casting is removed and tends to get smaller. This repetitive stress on the mold eventually causes a network of cracks to occur. If these cracks are permitted to become too large, molten metal runs into them and the casting can get stuck in the mold. The removal of the casting will scar the mold so much that it will be rendered useless.

A maintenance program should be set up to examine the mold periodically, and to grind out and weld any cracks that occur, and then grind or machine the mold back to size.

It is possible to design permanent molds, particularly pipe molds, so that when the molds are originally put into service, the pipe is produced at the minimum range of the pipe tolerance. As the mold is used, the heat checking finally develops. If suitable maintenance is kept, the molds can be re-bored up to three times and still maintain the pipe within the tolerance of the specifications.

DESIGN CONSIDERATIONS

Several factors must be borne in mind when designing a mold for a horizontal centrifugal casting machine. Since it is understood that a mold fails by the formation of thermal fatigue cracks, it follows that if a mold wall is extremely thin there can be very little or no stress in the mold wall.

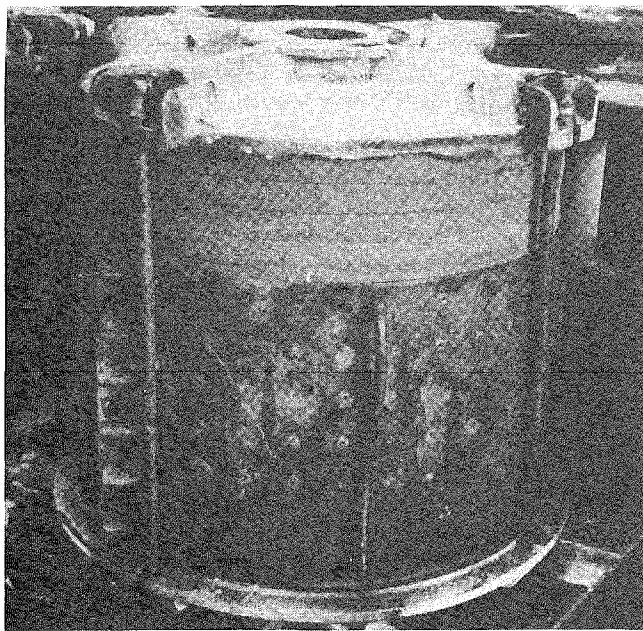


Fig. 4-4. An assembled stack of dry sand cores for steel casting.

When the mold is heated it expands and when cooled, contracts, and remains within the elastic limit. Thus, if suitable materials are used, the mold has a very, very long life. However, it is not possible to use a very thin wall for the mold since it is impossible to extract the resulting casting from the mold. The mold shrinks around the hot casting.

Several factors determine the necessary wall thickness for a cylindrical mold. Keeping in mind the fact that the thinner the wall section, the longer the mold life (and also the less costly the mold), we attempt to arrive at a proper design. However, if the mold is made with the wall section too thin, the mold will be subject to warpage. As a result, after only a very few castings are made, the mold would be warped and it would be impossible to remove the casting. This would be true even though the molds were thoroughly stress-relieved. Also, certain non-uniformities in the metal of the mold itself will cause warpage. Thus, it is necessary that a mold be heavy enough so that it will not warp. Naturally, short molds will warp less than longer molds. Accordingly, the longer molds require heavier wall sections for this reason alone.

It is also necessary that the mold be heavy enough to absorb the amount of heat that is given off during the solidification process of making a casting. The mold must be able to absorb the latent heat of fusion of the metal being cast, the superheat of the metal above the solidification temperature, plus some of the heat given off by the casting as it cools to the temperature at which it is extracted from the mold. Generally, the maximum operating temperature for the mold should not be in excess of 800F/427C. A good, normal operating temperature for a mold would be between 300–500F/150–260C, but operating temperatures in the range of up to 600F/315C can be quite satisfactory. It is thus apparent that if a mold wall is too thin, with respect to the weight of the casting being produced, the mold will attain excessive temperatures even for a single cast. Thus, the mass of the mold itself must be adequate to absorb this sudden input of heat.

Normally, most metal molds are water cooled. One method by which water cooling can be performed is by putting the mold in a water box and having water circulate around the mold. Another method is for the mold to be cooled by spraying water on the outside of it, along its length. Water cooling by either method is very efficient, with the result that mold temperatures can be maintained at a desired level. Normally, there will be an increase in the temperature of the outside of the mold very soon after the metal has been poured into the mold. However, when the water cooling comes into play it tends to cool the surface of the mold very appreciably. This is particularly true if jets of water impinge at high velocity against the outside diameter of the mold.

Consider, for example, a mold with a 4-in. (101-mm) wall section having a 10-in. (254-mm) wall section casting therein. After the mold has been spinning with the metal inside for several minutes, then water-cooled by spraying, the mold can be stopped and felt with one's bare hand. The mold will feel cool to the touch!

It must be further noted that if the wall section of the mold is excessively thick, we find that while we have little or no warpage occurring in the mold, we will increase mold cost and at the same time tend to decrease the overall mold life. Even so, it is general practice to make the mold wall thicker than necessary. This eliminates the possibility of warpage and other problems that might occur when excessively thin-walled molds are used.

Experimental data discloses that when cast iron is poured into a steel mold, the peak mold wall temperature is approximately 1450F/790C. From what we have said previously, we understand that the lower the peak wall temperature of the mold, the lower the stresses on the mold and, therefore, the longer its life will eventually be. Accordingly, it is highly desirable to reduce the peak surface temperature of the mold. This is one of the reasons for using a refractory insulating coating on the inside of the mold. The presence of such a coating very effectively reduces the peak surface temperature, and appreciably increases the mold life.

Even though an insulating coating is used on the inside diameter of the mold, the chilling effect of the mold on white iron, when cast, is not altered appreciably. Conversely, it is found that when producing an iron structure requiring a slower cooling rate (such as the production of type A graphite in iron castings), the appreciable thickness of the insulating mold coating *does* reduce the chilling effect. This is because the insulation increases the length of time required for the initial solidification of the iron and tends to produce a type A, or modified type A, graphite structure. Usually, in addition to the relatively thick mold coating, the mold is operated at an elevated temperature between 600 and 800F/315 and 427C. This will further reduce the initial cooling rate of the iron and thus produce the desired type A graphite structure.

Figures 4-5 and 4-6 show wall sections for molds of different diameters, in short lengths and long lengths, which are being used on a practical basis for the design of centrifugal permanent molds. When designing a permanent mold, allowance must be made for the pattern shrinkage for the particular metal being cast as well as allowance for the thickness of the mold wash.

Mold Pre-Treatment

After a mold has been made it requires a pre-treatment process before being put into service. The pre-treatment requires that the mold be heated to a temperature of from 200 to 300F/93 to 149C. The inside of the mold is then swabbed with a saturated solution of ammonium persulfate or other mild etchant. This will very slightly etch the inside of the mold as well as clean the mold of all oil or grease. Sometimes the inside of the mold is lightly blast-cleaned to provide a slightly rough finish. After the treatment, the mold should be cleaned thoroughly with fresh water.

The purpose of this pre-treatment is to remove all oil or grease that may be on the mold as well as to slightly roughen the mold surface. This will permit the mold wash that will be used to have better adherence to the mold. This treatment

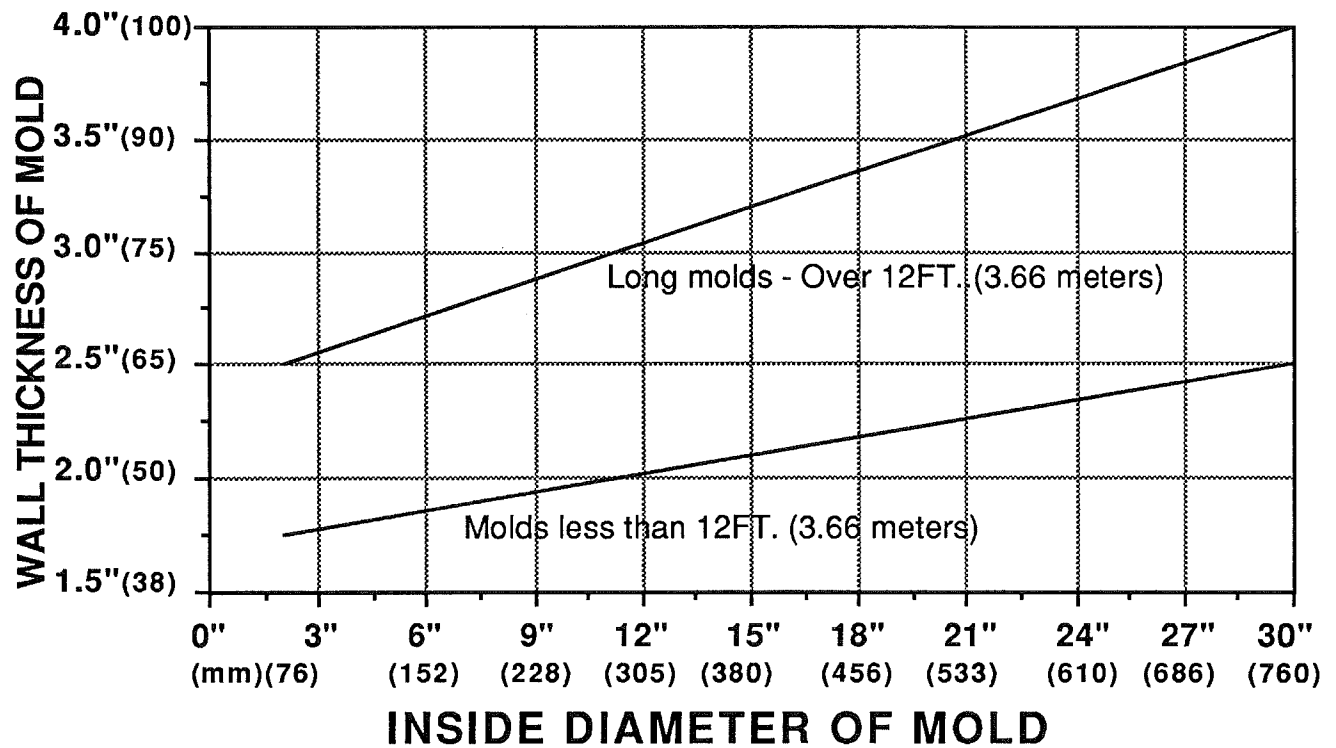


Fig. 4-5. Wall section of molds 1½–4 in. thick.

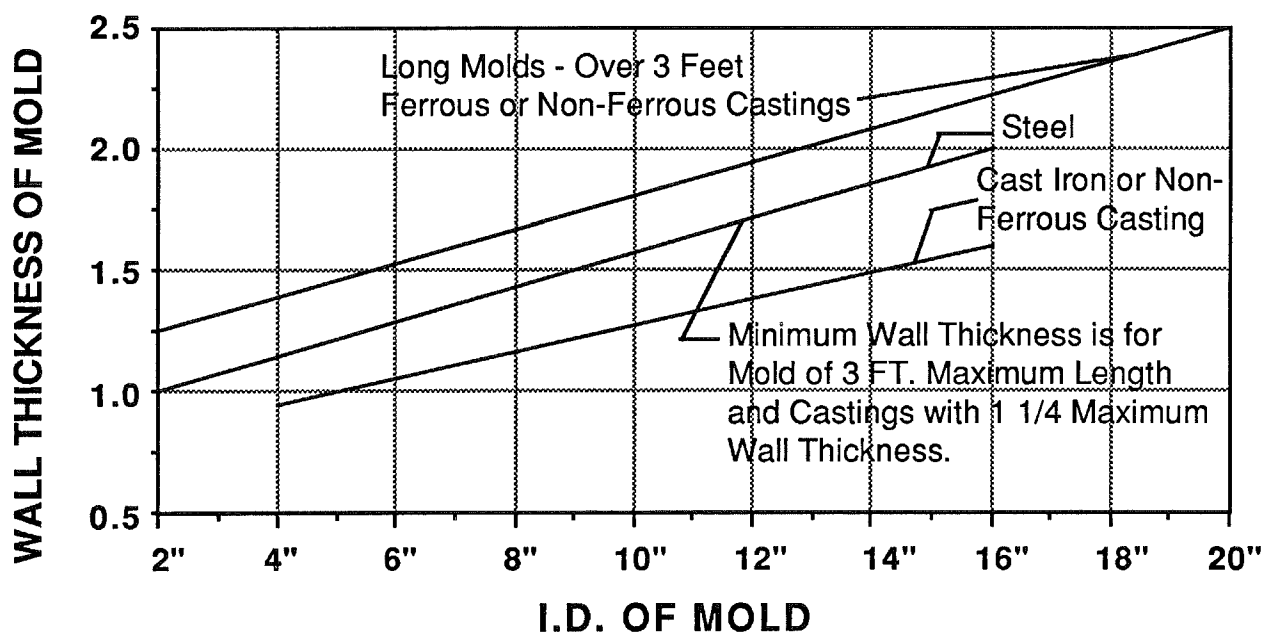


Fig. 4-6. Wall section of molds ½–2½ in. thick.

need not be performed each time the mold is put into service, but only on a new mold, or on a mold which has in some way accumulated oil or grease on the inside diameter.

Vertical Centrifugal Casting Molds

In the course of time various practical criteria have been developed concerning the design of molds for both vertical and horizontal centrifugal casting. In general, the mold for a vertical machine is similar to that for a horizontal machine insofar as it is composed of two end plates and a central body. The usual nomenclature for a vertical mold is slightly different; the lower end plate becomes the "bottom plate," the main section of the mold is the "body," and the top, naturally, the "cover." In vertical molds, the same design criteria apply regarding mold wall section as for horizontal machine molds.

When producing permanent mold castings in a vertical machine it is desirable to cool the bearings of the machine by circulating water. Many times the water, after moving vertically up through the shaft and cooling the bearings, is permitted to impinge against the bottom plate of the mold to make it cooler. Generally, the bottom plate of the vertical centrifugal casting mold will tend to be hotter than any other part. This is quite natural since the metal is usually poured onto the bottom plate.

Permanent Mold Cooling and Heating

Cooling

When cast iron permanent molds are used, it is not always desirable to cool the spinning mold with the usual powerful water sprays. Sometimes these molds are slowly cooled externally from the spinner by dripping small amounts of water onto the mold as it slowly rotates. This is not a very drastic cooling operation and is only suitable in over-and-under machines, or those machines in which the molds are not frequently reused. It is possible to use cast iron molds with air cooling although the efficiency of air cooling is very low. Therefore, because of the cooling problem, the use of cast iron molds in any sort of high-production machine is unsuitable.

Steel molds are recommended for applications requiring water cooling. In normal practice it is customary to start the mold spinning, pour the weighed amount of metal into the mold, and immediately thereafter turn on the cooling water. Depending upon the wall section of the casting being produced and the efficiency of the water spray against the mold wall, the water cooling may be continued during the entire spinning cycle or the water may be turned off sometime prior to the end of spinning.

In high-production machines, it is often found that even with continuous water cooling during the entire spinning cycle the mold will gradually get hotter and hotter until the temperature becomes excessive. In such cases, it is a good idea to apply additional water cooling to the mold during the period that it is being spun for reapplication of mold coating. This provides additional cooling time for the mold and tends to increase the permissible production rate.

For more information on cooling, see Chapter 7: Mold Heating and Cooling.

Heating

Molds require heating only at the initiation of the day's production. Once the molds are put into operation the problem is to cool them rather than heat them.

Permanent molds may be heated by any convenient method. One method is to place the entire mold in an oven external to the machine. The mold is then removed from the oven and placed in the machine at the proper time for production.

The molds can be placed in the machine and heated externally by means of gas burners or they can be heated internally by means of hot air provided by gas heaters. When molds are heated in the machine, the mold should rotate very slowly so as to develop even heat distribution. The bearings of the machine should be protected so that they will not be subjected to direct heat.

For more information on heating, see Chapter 7: Mold Heating and Cooling.

End Plate Design

Various methods can be used on molds to hold the end plate in position to prevent the metal from pouring out. Some of the variations in design are shown in Figures 4-7 and 4-8. Other designs can be used depending upon the ingenuity of the mold designer. It should be kept in mind that the simpler the method of attaching the end plate, the less trouble there will be in the normal operation of the mold and the machine. In many cases the molds require the attachment of one or both end plates with bolts. The

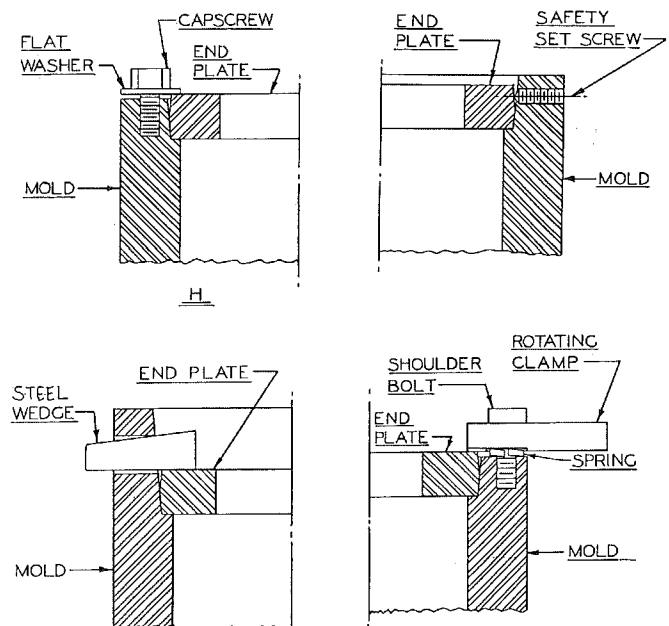


Fig. 4-7. Various end plate positions.

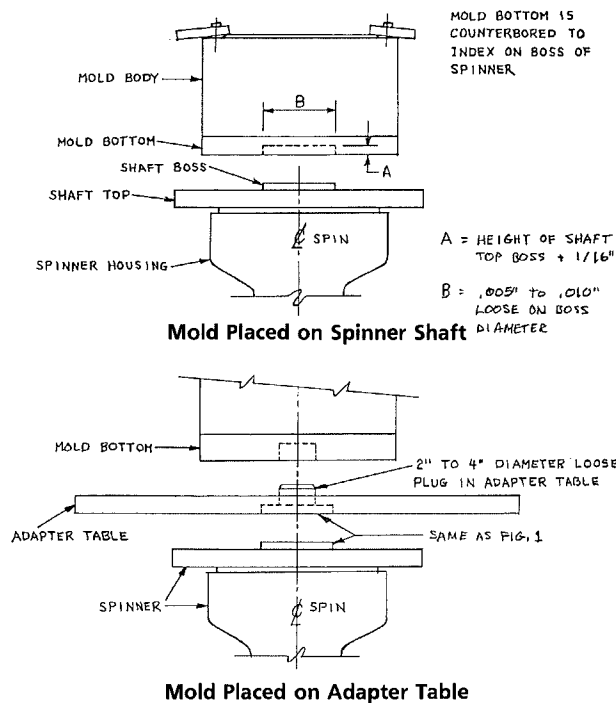


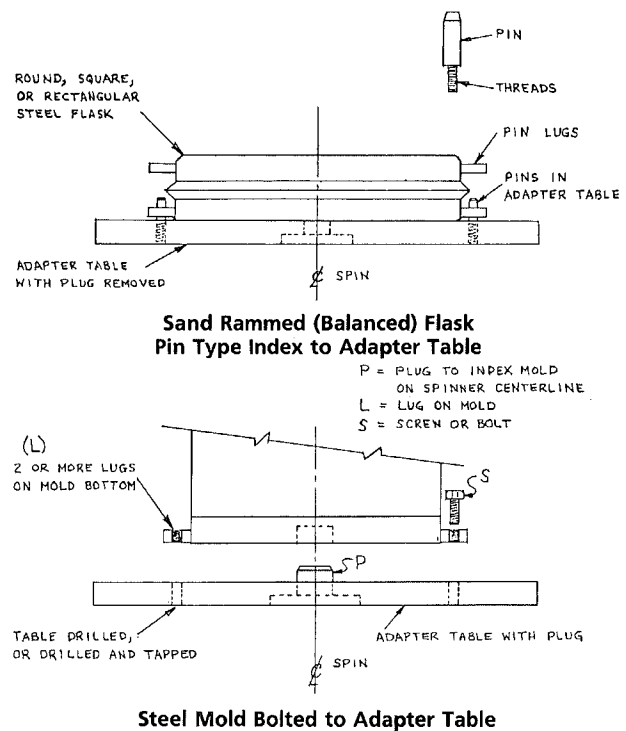
Fig. 4-8. Various adapter table designs.

bolt threads should always be adequately protected with a coating of molybdenum disulfide. If this is not done, the bolts tend to freeze in the mold after the mold reaches the normal operating temperature. It would then be impossible to unscrew the bolts from the mold.

Whenever possible, the end-plate for all horizontal molds is so designed that it will be reversible. If the plate begins to warp, which it will do in a dish-shaped fashion, it can be reversed and thus will straighten out. The same idea applies to the covers for vertical centrifugal molds. However, this reversible design cannot always be used because vertical centrifugal castings frequently are irregular in shape, with part of the casting configuration being formed by the cover.

Figure 4-7 shows various types of latches or devices that can be used to hold a top plate onto the body of the mold as well as to attach the mold body to the bottom plate. The attachment of the bottom plate to the mold is semi-permanent, whereas the attachment of the top plate to the mold is very temporary. It must be removed for the production of each and every casting. It is therefore quite important that the removal be accomplished very quickly.

In many vertical centrifugal casting operations it is more convenient to remove the entire mold from the machine and replace it with another identical mold. In this way, the top plate can be removed and the casting itself extracted from the mold external to the machine. Again, it is important when utilizing this practice to have a very simple method for attaching the vertical centrifugal casting mold to the face-plate of the machine (Fig. 4-8). It should be noted that in most vertical centrifugal casting operations it is not necessary to bolt the mold to the machine table.



If a mold is unbalanced, the problem should be corrected by remachining or otherwise, so it will not wobble. If it wobbles and vibrates, almost certainly the wall section of the casting will be thicker on one side than the other. Therefore, one should re-machine or do what is necessary to the mold to make it concentric and balanced. If this is done, it is not necessary to attach the mold to the machine table.

Special Mold Designs

In the case of very large diameter face-plate machines utilizing permanent molds, there is a problem in the attachment of the mold to the face-plate. If the mold becomes very hot during operation, external expansion is quite appreciable due to the increase in temperature when the metal is poured into the mold. When this occurs, the heads of the bolts or the bolt washers will necessarily have to either bend or slide to permit the mold to expand. In the event that the clearances are too close, the bolts can be partially sheared due to the expansion of the hot mold. Also, since the mold will expand but may not move exactly radially from the center, the mold can be eccentric; therefore, the center of the inside diameter of the mold may not coincide with the axis of rotation. This would cause the mold to vibrate when rotated, resulting in castings having one side thicker in wall section than the other.

It is therefore important that this expansion behavior be taken into account when designing the mounting of the mold to the face-plate. It is equally important in such an application that the bolts be made of soft low-carbon steel, rather than high-strength heat-treated steel. The low-carbon steel bolts will tend to deform rather than break off when high stresses develop.

Gates and Risers (Vertical)

INTRODUCTION

The feasibility of centrifugally casting a part is determined by the distribution of metal sections. A short discussion of the gating involved will help clarify this.

In its usual and simplest form, the gating of centrifugal castings involves a single gate that combines the function of gate and riser. The last part of the metal to solidify in the mold cavity should naturally be the gate. Thus, the principle of directional solidification is used, in which solidification of the metal in the mold cavity begins at locations farthest from the gate, and progressively proceeds toward the gate or source of fluid metal. This fluid metal "feeds" the parts of the casting progressively as the metal cools and solidifies, producing a solid, dense casting. The centrifugal force greatly magnifies this feeding action and produces a still greater metal density in the casting than would otherwise result.

At 1000 ft (305 m) per minute peripheral velocity, the equivalent head of a centrifugal casting would be 30 ft (10 m)! This is equivalent to a pressure of 102 lb per square inch (7 ATM) in the case of copper-base alloys (density of 0.28 lb/in.³). We compare this with the customary static casting which has a head less than 1 ft (305 mm) high. From this, we see that better feeding action results; therefore, it should be possible to feed through thin metal sections into heavier sections more readily than in static casting.

CALCULATING SIZE

The method of calculation discussed in this section involves several preliminary assumptions. First, it is assumed that all metal poured into the mold arrives there at the same temperature and that the temperature of mold surfaces is the same at all points in the mold. This naturally assumes that the mold is all of the same composition, without the use of either external or internal chills.

The above conditions are most nearly obtained in centrifugal casting where the gate serves as a feeder, and in blind-riser method of static casting when the gate directly enters the riser itself. Thus, the connection between the riser and the casting serves both as a gate and feed passage. In actuality, however, the temperature is not the same. Immediately after pouring, the metal farthest from the gate

is lowest in temperature. The temperature increases progressively toward the gate, with that nearest the gate being at the highest temperature. This is an ideal condition for directional solidification.

Cooling Factor

Where such a temperature gradient exists, it will be found that the actual size of gates and risers, as calculated by the method to be described, will be comparatively small since the method assumes that all metal arrives in the mold at the same temperature.

In describing this method the term "cooling factor," or C.F. will be used. The cooling factor is a relative measure of the time required for the casting to lose heat to its surroundings, or how quickly the metal will solidify. During the period of solidification, the liquid metal inside the casting will decrease in volume and additional metal will be required. For a gate or riser to supply this feed metal, it is necessary that the riser freeze more slowly than the casting itself. Therefore, the cooling factor of the gate must be larger than that of the casting.

Thus, by definition, we have a measure of the rate at which the casting will solidify. The greater the cooling factor, the greater the cooling time for the casting. However, most castings do not have uniform wall sections, resulting in a condition whereby the heavier sections of the casting supply feed metal to the thinner sections. The thinner sections are free of shrinkage, but the problem lies in the heavy sections, and those less adequately fed, which may contain shrink cavities.

The solution to the problem is simple, inasmuch as it is necessary to feed only the heavier sections of the castings, which require feeding from external sources. In consequence, the cooling factor can be more simply defined as:

$$\text{C.F.} = \frac{\text{Area of section of casting}}{\text{divided by the perimeter of section of casting}}$$

The cooling factor may be calculated as follows:

$$\text{C.F.} = \frac{\text{Volume of casting}}{\text{divided by the surface area of casting subject to cooling}}$$

For demonstration purposes consider a simple example, such as a ring having dimensions of 12-in. (305-mm) outside diameter, 10-in. (254-mm) inside diameter, and 2-in. (51-mm) height (Fig. 5-1). The cooling factor of this ring is calculated as follows:

$$C.F. = (2 \times 1) / (1 + 2 + 1 + 2) = 0.333$$

Assume for the time being that the casting desired is to be cast centrifugally. This casting would be gated with the gate contact on the inside diameter. From the definition of cooling factor (and from experience), the gate or riser that will cool most slowly has a circular cross-section. However, since it is not always practical in molding to use a gate of circular cross-section, the gate used is generally of square or rectangular cross-section. Whenever possible, it is preferred that rounded corners be used in gating. This will result in a more favorable cooling pattern for the gate. In this case it will be assumed that a gate of square cross-section will be used because, as will be shown later, a square has the highest cooling factor of all rectangular sections. Thus, if "A" is called the length of the side of the square, the cooling factor of the square will be as follows:

$$C.F. = (A \times 2) / (4 \times A) = A / 4$$

The minimum allowable cooling factor for the gate is the same as that for the casting. Therefore,

$$C.F. = 0.333 = A / 4 \text{ and } A = 0.333 \times 4 = 1.33$$

Accordingly, the minimum value of "A" is 1.33 in. (33 mm). To be on the safe side, a slightly larger even dimension, such as 1½ in. (1.375, or 35 mm) would be used.

From the equation we calculate the cooling factor of the 1½ in. (35 mm) square gate to be:

$$C.F. = 1.375 / 4 = 0.344$$

It should be noted that the size of the gate is determined by the rate at which the gate cools; the gate must freeze later than the casting.

Number of Gates

It has not been possible to find an exact method of calculating the number of gates required for a given casting, but experience indicates the following as a general yardstick:

Diameter of Casting	Number of Gates Required
Up to 12 in. (305 mm)	2
12 to 18 in. (305 to 457 mm)	3
18 to 24 in. (457 to 610 mm)	4
24 to 30 in. (610 to 762 mm)	5
30 to 40 in. (762 to 1016 mm)	6

Thus for the 12-in. dia. ring casting under consideration, two gates are required (Fig. 5-2).

The actual number of gates required usually will be somewhat less than shown in the above table. This is because each gate will feed a section extending approximately 9 in. (229 mm) from either side of its junction with the casting. This will be determined to a considerable extent by the exact shape of the casting, i.e., whether square or rectangular. Other factors are section size and the amount of metal in the casting (whether the casting is large and heavy, or small and light).

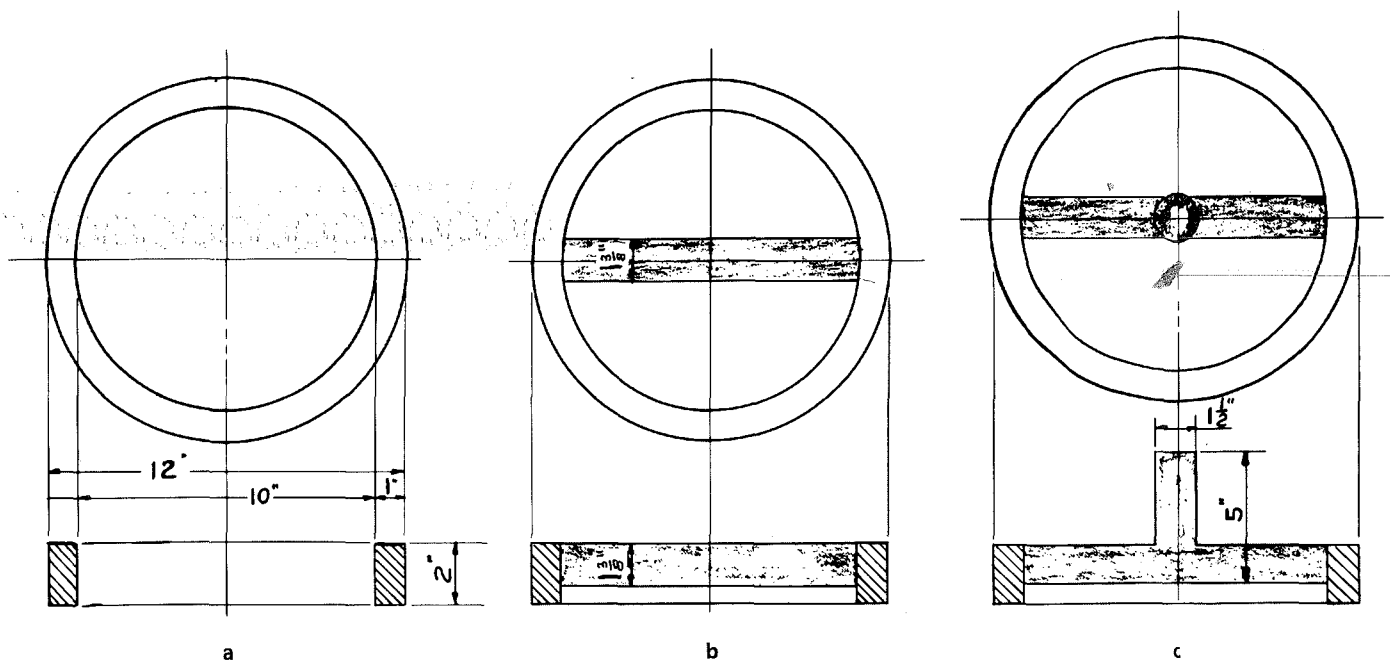


Fig. 5-1. a) Sketch of ring casting having 12-in. O.D., 10-in. I.D., 2-in. high; b) same ring casting illustrating position of two gates; c) same casting illustrating downgate determined as required for feeding inside gate. Cooling factor is same as for square gate.

Complex Casting

As an example of a somewhat complex casting, consider a valve body. Here the heaviest section is the flange; if the flange can be fed adequately, the remainder of the valve body will be perfect. This assumes that the valve body has been properly designed from the foundry standpoint, so that directional solidification can ensue when the casting is poured; otherwise pads or chills may be required.

Figure 5-3 shows the cross-section of such a valve casting. It is necessary merely to measure the dimensions of the flange in order to determine the size and type of gating necessary. Assuming that the thickness of the flange is $1\frac{1}{4}$ in. (32 mm), with the face $2\frac{1}{2}$ in. (63 mm) wide, the cooling factor is calculated thus:

$$\text{C.F.} = (1.25 \times 1.25) / (2.5 + 1.25 + 2.5 + 1.25) = 0.416$$

To be exact, it would be necessary to subtract the area of that part of the casting attached to the flange from the amount of cooling surface that the flange encounters. However, if this step is neglected, a safety factor is provided for the size of the gate obtained and the calculation is simplified. Thus, the size of the gate required, calculating as before, would be:

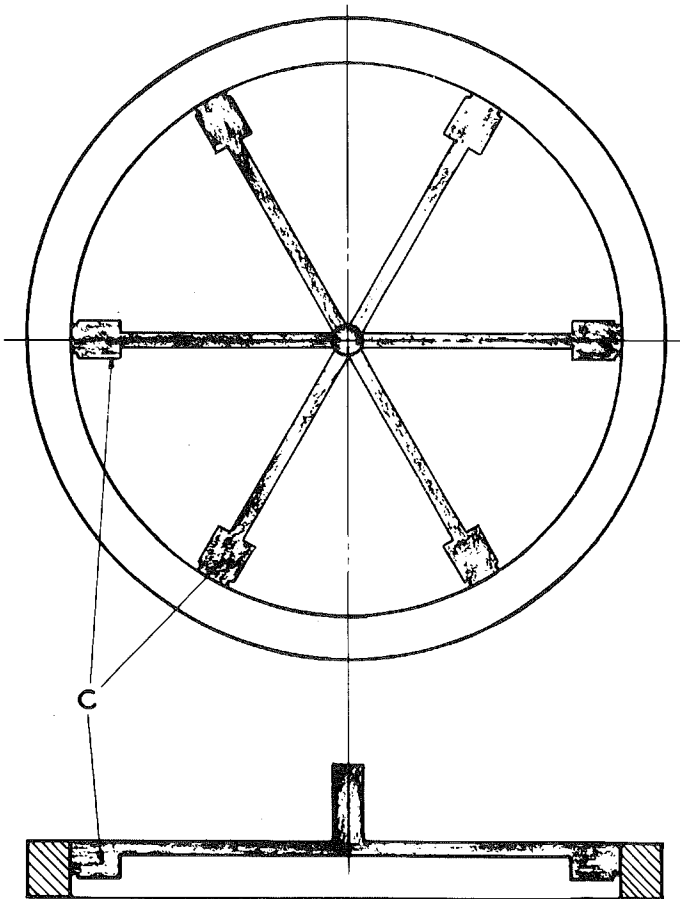


Fig. 5-2. For large castings, as in the wheel casting shown, it may prove advisable to provide the feed metal (c) in the gate itself, with small gates or runners radiating from the center.

$$4 \times 0.416 = 1.656 \text{ in. (42 mm)}$$

The next larger convenient fractional size is $1\frac{3}{4}$ in. (44 mm). The remainder of the calculations would be carried out in the same manner as shown earlier.

CALCULATING SPRUE (DOWNGATE) SIZE

The experimental ring casting requires a sprue (downgate) to feed the side gates of the size selected. Naturally, a round sprue is used and the calculation is as follows:

$$\text{C.F.} = (\pi \times D^2) / 4 \div (\pi \times D) = D / 4$$

Thus, the sprue must have a diameter slightly larger than $1\frac{3}{8}$ in. (35 mm). A diameter of $1\frac{1}{2}$ in. (38 mm) might be selected, giving a cooling factor of 0.375 for the sprue.

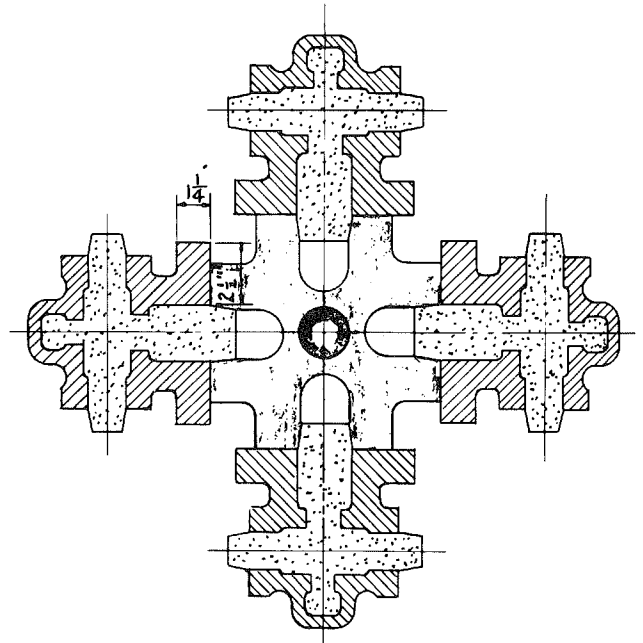


Fig. 5-3. Cross-section of valve body casting. Size and type of gating required can be calculated from the dimensions of flange and face.

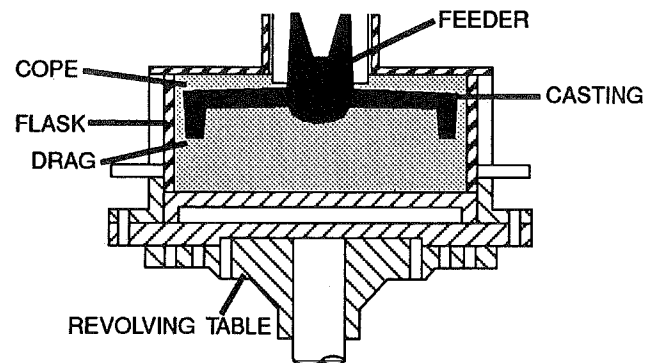


Fig. 5-4. A semi-centrifugally cast flywheel.

Adequate Feeding

It is entirely possible that the cross-sections of the gate and sprue have been properly selected to freeze later than the casting but may be of such volume as not to contain adequate metal to feed the casting. The height of the sprue must be adequate to supply the amount of feed metal required for both the casting and the in-gates.

If this casting were steel, it would weigh approximately 20 lb (9 kg). The volumetric shrinkage of steel is approximately 3.5%; but to be safe, and because many castings have irregular contours, which make exact calculation impractical, a figure of 10% is used. The total weight of the side gates used in this case is 4½ lb (2 kg). Thus, a total of 24½ lb (11.1 kg) requires feeding. Ten per cent of this is approximately 2½ lb (1.1 kg), the amount of metal required in the downgate. Since each inch of the 1½ in. diameter downgate weighs ½ lb, a downgate measuring at least 5 in. (127 mm) high would be required.

The size of the gates that contact and actually feed the casting, and the diameter and height of the sprue necessary

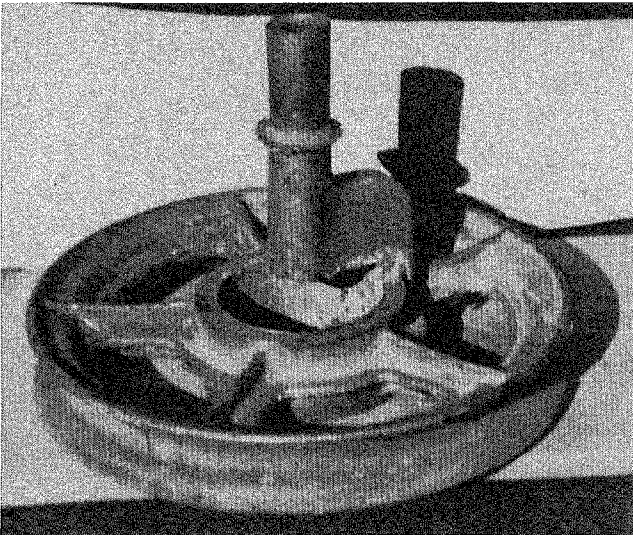


Fig. 5-5. A semi-centrifugally cast steel sheave.

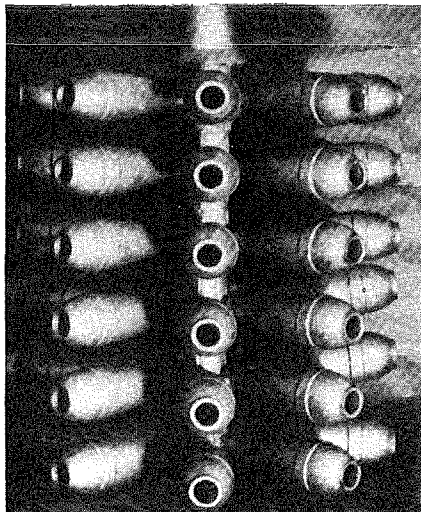


Fig. 5-6. Steel stack molded mortar shells.

to feed an adequate amount of metal to the in-gates and casting, have now been calculated.

In many cases the diameter of the downgate will be a figure inconvenient to use in foundry practice. For example, instead of a 1½-in. (38.1-mm) diameter downgate, a 2-in. (51-mm) diameter downgate could be used. However, in this case it would not be necessary to use so tall a downgate, since the 2-in. (51-mm) downgate need only be 2.8 or 3 in. (76 mm) tall. A larger gate may always be used, because its cooling factor will be larger and, thus, it will solidify later.

METAL ECONOMICS

It is not always necessary or economical to have the downgate equal to the calculated diameter and height in order to feed the castings as well as the gates. For large castings, it may be advisable to provide the necessary amount of feed metal (c in Fig. 5-2) to the gate itself, and to use small gates or runners coming back to the center. This is a matter of metal economics. Generally, it is possible to obtain yields of more than 75% using this method.

It is interesting to note that the amount of feeding provided by a circular riser or feeder is exactly the same as that of the smallest size square riser in which it could be placed.

C.F. for circular gate = Area divided by Perimeter =

$$(\pi D^2 / 4) \times (1 / \pi \times D) = D / 4$$

C.F. for square gate = Area divided by Perimeter =

$$D^2 / (4 \times D) = D / 4$$

Where D = the diameter of the circle and also the side of the square.

For a circle of diameter D and a square of side D, the cooling factors are the same. Thus, the amount of metal in the corners is wasted.

A sprue can act as a gate and riser. The semicentrifugal casting method is used to manufacture castings of circular, annular, or disc shape, such as gears, wheels, tires, or plates. The mold is always rotated about the axis of the part and the centrifugal force exerts pressure from the center towards the rim to facilitate filling of the mold and assist, to some extent, in directional solidification (Figs. 5-4 and 5-5).

A semicentrifugal casting machine consists of a flat round table supported and rotated by a vertical shaft, driven by a hydraulic or electric motor. The size of table, motor, and bearings vary with the size and weight of the castings being produced.

The sand molds and the flasks containing the sand, or metal molds, are fastened to the table with the axis of the molds coinciding with the axis of the table and shaft. The molds are poured either singly or, where possible, stacked on top of each other about a central sprue. Figure 5-6 demonstrates how a stack of mortar shells were positioned about the central sprue. The sprue serves both as a gate and riser for these castings.

Mold Coatings

INTRODUCTION

It is normal practice in centrifugal casting work to coat the inside diameter of the mold with a mold coating, whether it be a permanent mold or a sand mold. The use of this material serves two functions, one of which is to provide a parting agent so that the casting can be more readily removed from the mold, and the other is to serve as an insulating agent to reduce the chilling effect of the metal against the relatively cold mold.

The life of a permanent mold is affected directly in proportion to the peak mold surface temperature. Any effort that is used in the production of castings that reduces the peak mold surface temperature will increase the life of the mold.

Various methods are employed to reduce the peak mold surface temperature. A mold coating, because of its insulating qualities, will reduce the peak mold surface temperature. Also, an excellent practice is to remove the casting from the mold as soon as possible. This will further reduce the peak mold surface temperature.

The life of a mold is a very complex matter. Basically, it is a fatigue problem. The higher the tensile strength of the material of the mold or, better yet, the higher the fatigue strength of the mold material, the longer the mold life. As the mold goes through its temperature cycle, fatigue stresses are set up in the mold material. The mold material with the highest fatigue strength limits and those molds subjected to the lowest stresses will generally have a longer life.

It would be ideal to be able to make centrifugal castings, or any other permanent mold castings, in a mold that did not require any type of coating. The use of graphite or carbon inserts inside a steel jacket or container is an effort to obtain a semipermanent mold that does not necessarily require any mold coating. Unfortunately, the carbon or graphite inserts have a very short life and are fairly expensive. Therefore, mold coatings are generally used for most centrifugal casting productions, and the following information applies to both horizontal and vertical centrifugal permanent molds.

IDEAL CHARACTERISTICS

An ideal mold coating should be very inexpensive, utilizing readily available materials. It should be very simple to mix or produce. It should protect the mold from extremely high temperatures in order to increase the mold life. It should be an insulating material that slows down the initial rate of solidification of the molten metal so as to reduce the possibility of cold shuts or laps during the casting process. The wash should be stable and capable of being stored for extended periods of time without deterioration.

Mold spray equipment usually has pipes and hoses, which can clog up or settle out. Therefore, the coating should contain some material, such as a gelling agent, so that it can be used in long pipes or hoses, which are used for pumping the coating from one location to the other. Ideally, the coating should not be corrosive or erosive, which reduces the life of the spray tips in the spraying systems.

Another highly desirable feature is that the coating should dry very quickly when applied to the mold. It should adhere to the mold tenaciously so that the flowing molten metal will not erode the coating and separate it from its contact with the mold wall. However, if the coating adheres too strongly it will never uniformly come off the mold, making it rather difficult to continuously produce castings in the same mold. Thus, the ideal mold coating is one that removes itself automatically with the casting, so that no coating remains in the mold.

Another essential characteristic of mold coating is that it must have some permeability. One defect, which has been encountered in centrifugal casting work over a period of many years, is known as the "pinhole defect." This defect is caused by moisture retained in the mold coating or some constituent of the coating, which turns to a gas when the molten metal comes into contact with the coating. The gas that is formed will attempt to get out of its existing location. The easiest path, in most cases, is for the gas to go through the molten metal, which, at that moment, is in the process of solidifying. The result is that very small pinholes exist at the particular locations in the casting where the gases came out of the mold coating. For further information, see Chapter 13: Troubleshooting—Defects.

EFFECT ON SURFACE FINISH

The refractory coating can be applied to the mold to produce a very smooth coating or a very rough coating. In some cases, such as in the production of cast iron cylinder liners that are later to be inserted in a die casting machine and have aluminum die cast around them, it is desirable that the outside of the casting be very rough. This rough surface produces a very good mechanical bond between the aluminum and the liner. In other cases, it is desirable for the outside of the casting itself to be very smooth in the as-cast condition. This requires that the inside surface of the mold be very smooth, to provide the ultimate smooth casting.

COATING INGREDIENTS

Bentonite

There are two basic types of bentonite and they are generally classed as "western" and "southern." Western bentonite has excellent gelling properties and is usually suitable for use in coatings or slurries used for centrifugal casting. Southern bentonite is unsuitable for this application.

Western bentonite is available in several different grades and trade names. The more expensive western bentonites are most suitable for use in centrifugal casting coatings. They are similar in chemical action from batch to batch and sack to sack. Only a small amount of bentonite is used in a mold coating and the proportions must be carefully determined. Once the formula has been determined it should be adhered to. It is extremely important that close control be used in purchasing the raw materials as well as methods of mixing and proportioning the ingredients. In many plants the coating is prepared under the control of the laboratory. The cost of the mold coating is a very small part of the cost of producing a centrifugal casting but is probably one of the most important factors in determining a low scrap rate.

Silica Flour

Silica flour is the major ingredient in mold coatings. In some places it is prohibited by law. A more expensive ingredient is aluminum silicate, which may be substituted for silica flour.

PICK-UP

When a mold is spinning, the velocity of the coated surface is quite high. The molten metal, when introduced into the mold cavity, has zero rotational velocity. The result is considerable sliding of the molten metal until it attains, by means of friction, the rotational speed of the mold itself. Since the molten metal must be quickly accelerated to the rotational speed of the mold, it is desirable that the surface of the coating be rough: the rougher the surface the quicker the "pick-up" will be. However, when we wish to produce a very smooth casting, we cannot have a rough surface to assist in the pick-up. In such cases, various special techniques are required to overcome this difficulty. These are taken up in Chapter 9: Pouring.

Another important factor that influences pick-up is the viscosity of the metal. If the metal is poured into the mold at a high temperature it will usually have very low viscosity. As the metal cools down, the viscosity will increase and, thus, the pick-up will increase due to the increased friction. In the case of vertical centrifugal casting, the metal will lay in the bottom of the mold as it cools until it becomes viscous enough to have the pick-up necessary to accelerate it to the speed of the mold, thus forming a tube. In horizontal centrifugal casting, the metal will tend to ride up inside of the mold and then "rain" or fall off the top of the mold until it attains the rotational speed of the mold.

After considering all of the above, it can be realized that the graphite coatings, which are sometimes used on permanent molds, are very unsatisfactory coatings for centrifugal casting. Graphite or carbon coatings, as usually applied, have no permeability and are not a particularly good insulator. Graphite coatings will usually result in quite a smooth coating, which is, again, not particularly desirable. It is inherently slippery, whereas for a coating we really want a material that produces much friction for the molten metal as it's being poured against the mold.

There are many different proprietary coatings available, some of which perform very well and others not so well.

SPRAY COATING OF MOLDS

There are various methods of spray-coating the mold. In the case of De Lavaud pipe machines, it is the usual practice to have a tube attached to part of the pouring spout. As the metal comes off the pouring spout a dry mold coating material is blown out the end of the tube onto the mold, thus the molten metal immediately encounters the mold coating. This is a continuous affair as the spout remains stationary, and the centrifugal casting machine moves longitudinally or vice versa. When the machine is advanced so that the pouring spout is wholly internal to the length of the mold, the rotation is started. The machine is retracted as the metal pours into the mold and the dry coating material is applied. This continues until all of the metal and all of the coating material (basically ferrosilicon) has been put into the mold simultaneously.

Figure 6-1 shows a mold cleaning brush used to clean the inside diameter of a mold. This brush is ordinarily used in a mold rotating at a low speed. It is not usually necessary to clean the mold after each casting. A proper coating should adhere to the casting and none should remain in the mold. The mold can be blown out with compressed air and the spray wash reapplied. Once or twice a day is usually more than sufficient for the use of the mold cleaning brush.

All other types of horizontal centrifugal casting methods utilize a long lance that moves longitudinally while the machine remains stationary. In some cases, the lance is manually located on the center of the mold and advanced and retracted through the length of the mold while it is spinning. Figure 6-2 is typical for an automatic spray car, which has the "tracks" elevated above the floor level and is relatively impervious to sand on the tracks.

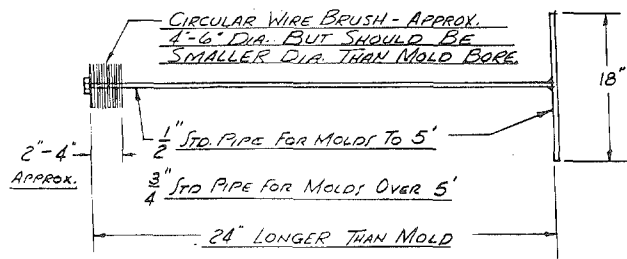


Fig. 6-1. This mold cleaning brush should be carefully inserted into the slowly spinning mold.

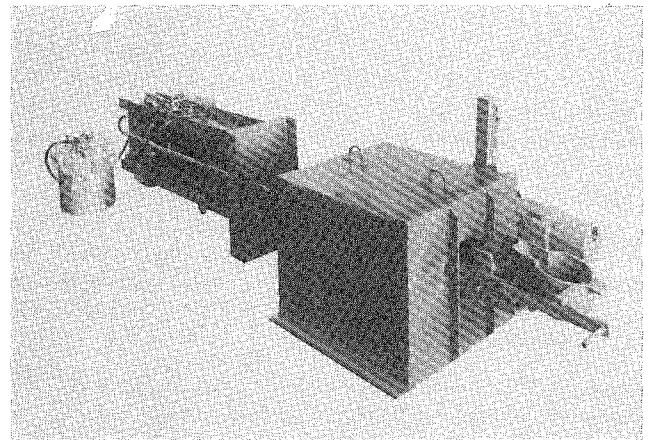


Fig. 6-2. Horizontal machine with an automatic "car" type spray lance and pouring device.

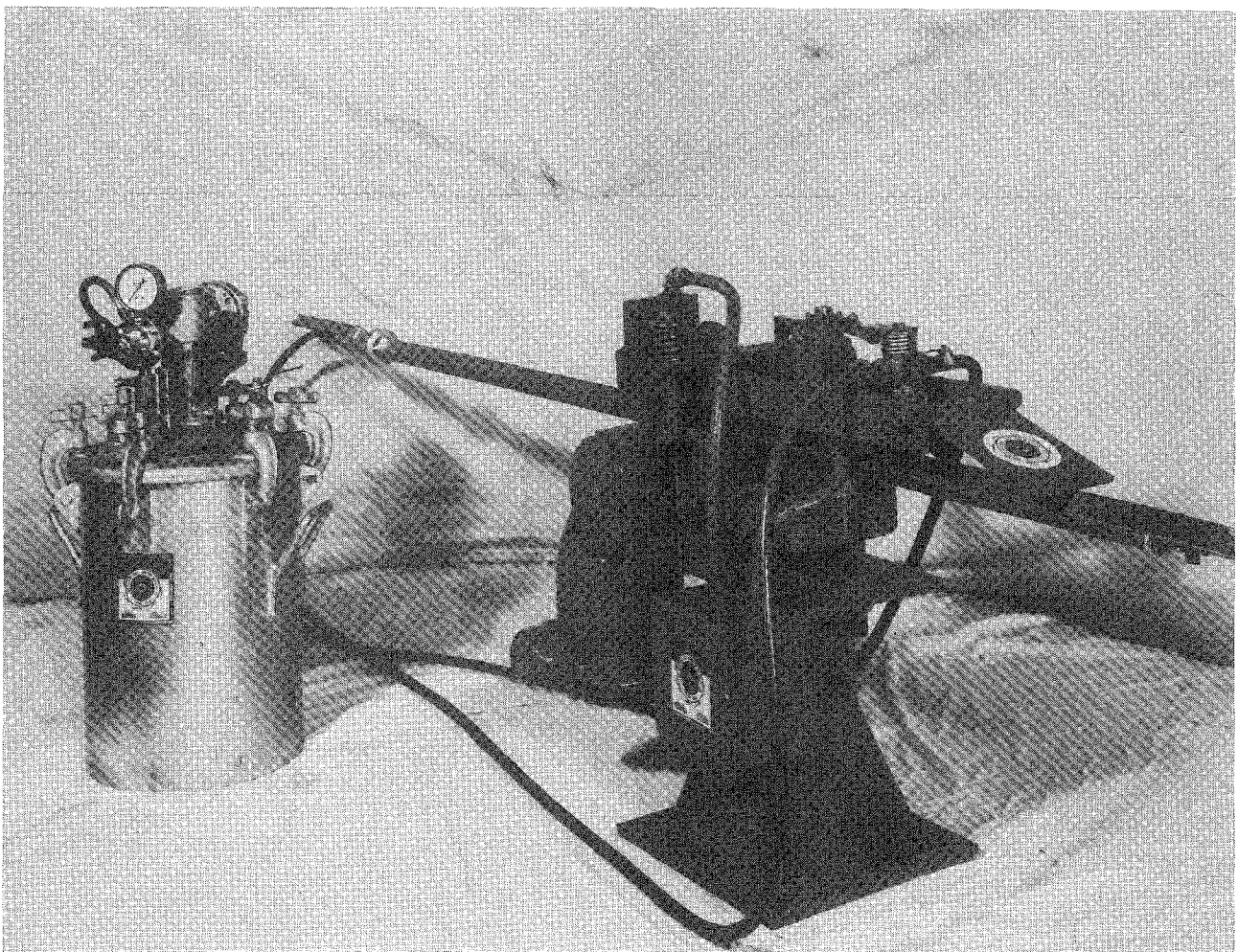


Fig. 6-3a. A Rolance for spray coating molds.

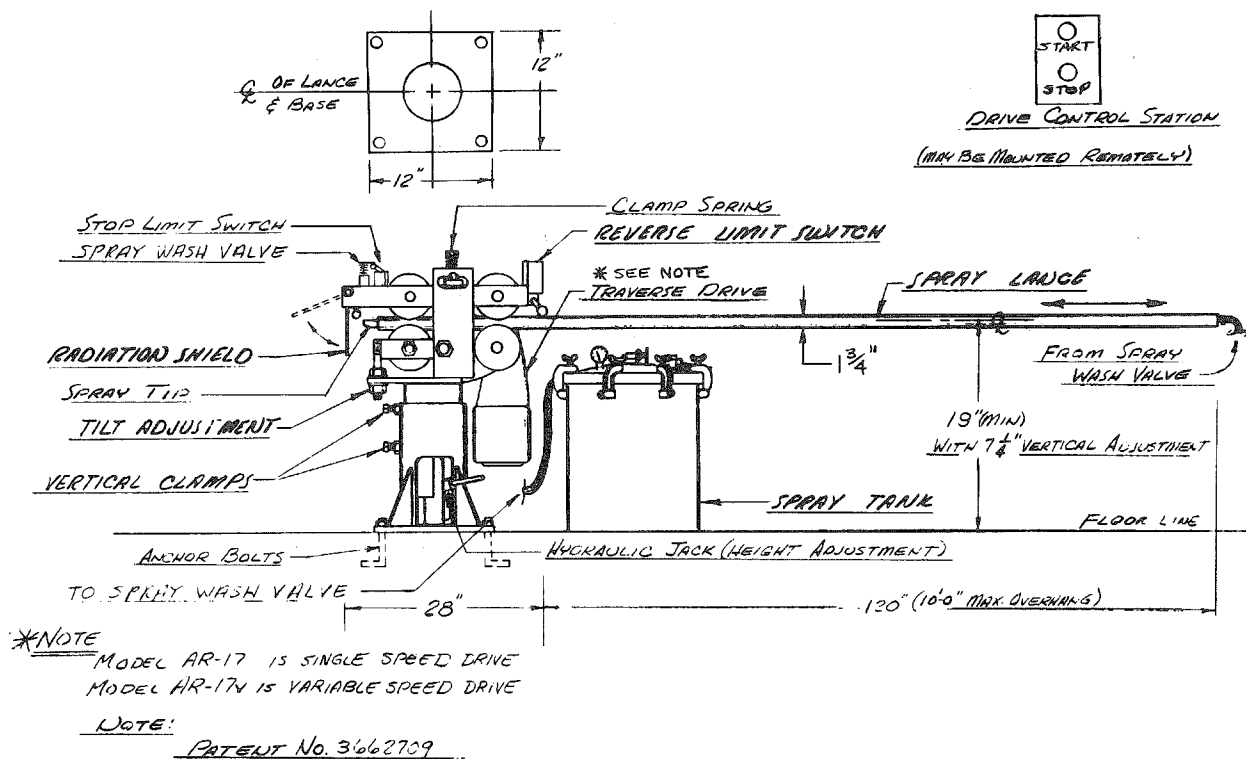


Fig. 6-3b. Diagram of automatic Ralance.

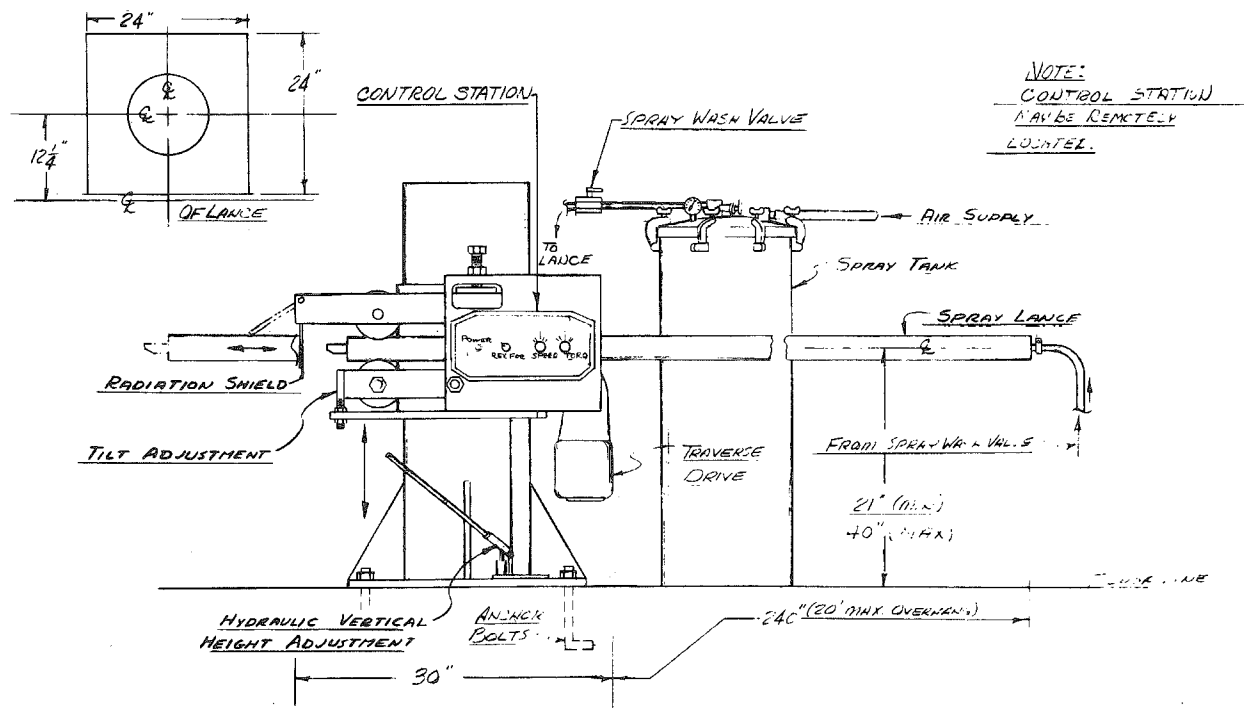


Fig. 6-3c. Diagram of manual Ralance.

Another device that is widely used is a spray car, which is a small car supporting the lance, which moves longitudinally into and out of the mold. These spray cars are adjustable, vertically, so that the lance can be centered with respect to the mold. The spray car may be moved longitudinally by an electric motor or a hydraulic cylinder. A pneumatic cylinder would not be satisfactory because of its possible irregular motion.

While spray cars that operate on tracks are quite satisfactory, in the course of time, dirt, sand, and other particles are apt to get onto the track. This causes the car to bump as it rides along the track, and causes the spray lance to vibrate. If small diameter molds are being used, it is apt to cause the spray lance to contact the inside diameter of the revolving mold. This causes a "wrap-up" and effectively destroys the lance.

In order to reduce the wrap-up tendency to a minimum, a device called a Rolance* (Fig. 6-3a,b,c) has been developed. It utilizes no tracks and causes the lance only to move in and out of the mold. The lance is driven by pinch rolls that are elevated off the floor and are in such a position that dirt or other materials do not accumulate on them. This device permits much smaller diameter molds to be utilized and has no limitations as to the length of the lance that can be used.

* Patent No. 3662709, Centrifugal Casting Machine Company.

Lances

Spray lances are made in many different designs. The essential characteristics of a spray lance is that it must convey, through its length, the fluid that is to be sprayed against the mold, and it should support a suitable spray tip. Lances that are uniform on the outside and telescopically tapered on the inside are being used. This design produces a relatively stiff lance (minimum tip deflection or sag), but has the disadvantage of being large in diameter. Even though the large diameter adds rigidity to the lance, the tip can come relatively close to the mold wall because of the slight sag.

Externally tapered lances start out with one size of tubing and are progressively reduced in diameter until the spray tip end is reached. These also are quite stiff, but have the advantage of a smaller diameter at the tip which allows more space to move about without touching the inside diameter of the spinning mold.

Calculations disclose that the weight at the tip of the lance is of the utmost importance in determining its stiffness. Therefore, the spray tip is frequently made of light-weight high-temperature plastic or aluminum, and is small in diameter to reduce this weight.

In addition to the various designs of tapered lances, round- or square-shaped lances are used also. A square-shaped lance (Figs. 6-3 and 6-4) is generally used in a Ro-

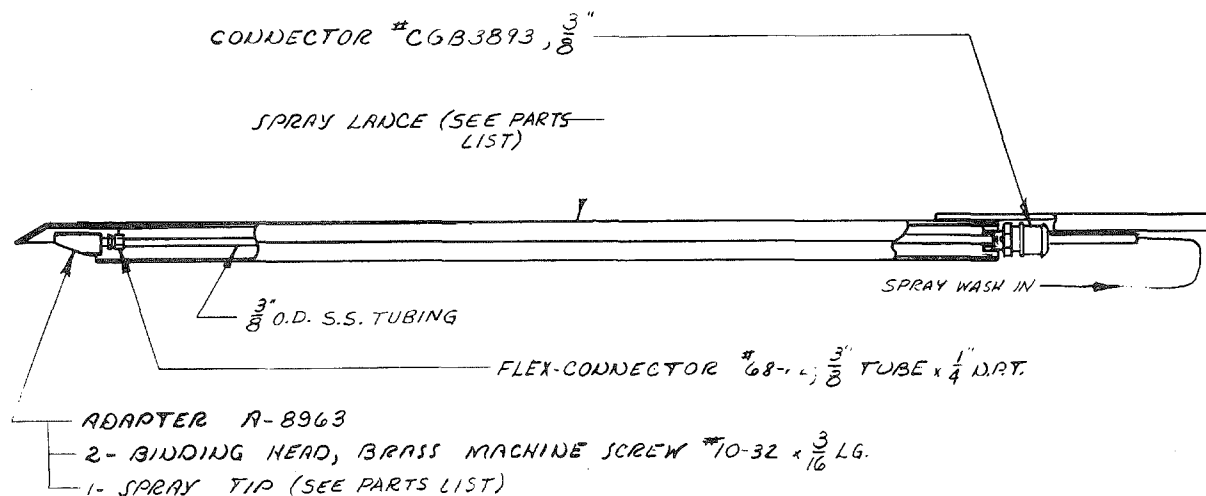


Fig. 6-4. Diagram of spray lance assembly.

lance, as it is not desired to have the lance rotate during its longitudinal advancement. A round lance will tend to rotate, which would tangle up the hoses feeding the coating material to the center tube in the lance. While lances are almost invariably made of steel, the internal tube, which carries the coating material, should be made of stainless steel to prevent corrosion. The usual coating materials cause ordinary steel to corrode very rapidly.

Spray Tips

There are many different wash materials or "slurries" used for coating molds. The spray tips themselves may consist merely of an open-ended tube or pipe, which permits the fluid to run out onto the revolving mold. The fluid then produces a centrifugal casting on the inside of the mold, which immediately dries and forms the mold coating. This system, with suitable formulations, is very satisfactory. However, it will frequently produce a spiral type of coating, which will cause a spiral effect on the outside diameter of the resultant casting.

To eliminate the spiraling effect (Fig. 6-5), a spray tip is used, which causes the slurry to come out of the end of the lance in the form of a fan spray that is oriented longitudinally. This effectively eliminates the spiraling effect.

Figure 6-6 illustrates the appearance of a mold with properly applied coating.

Tips are available in various capacities so that more or less slurry can be deposited in the mold. The results would also depend on the pressure being utilized, the viscosity of the slurry, the diameter of the mold, and the longitudinal traverse speed of the lance. The pressures that are used in the spray coating systems should be relatively low, as the lower the pressures and velocity at which the coating moves during its spraying period, the longer the life of the spraying equipment.

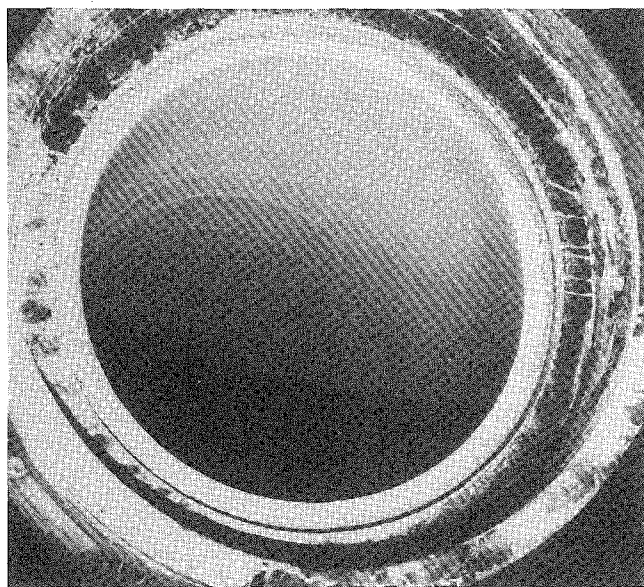


Fig. 6-5. Mold coating applied incorrectly will create spiral effect and show up on casting.

It is normal to apply coating to the inside diameter of the mold in two passes; one pass in and the other pass as the lance is retracted from the inside diameter of the mold. However, only one pass may be used just as well. Usually, in order to produce the very smoothest types of coatings, a small amount of the coating is applied to the mold in as many as six or eight passes.

Other types of tips can be used. One type is designed to rotate due to the pressure of the coating. It produces a rather smooth coating as it disperses the wash in very fine particles. Another type introduces compressed air into the fluid causing them to mix and spray fine particles onto the mold as the lance traverses.

It is very important to realize that the coating, when it actually contacts the hot mold, should be a liquid or slurry; not dry. If the spray tip is a distance of 12–18 in. (305–457 mm) away from the mold surface, it is possible for the wash to dry in mid-air before it reaches the mold surface, particularly if it is finely dispersed. This will cause a dry powder to exist on the inside mold surface. The powder will be washed away by the molten metal, and the casting produced will not have a smooth surface. In any case, it is essential that the coating, when it actually contacts the mold, be moist; finely dispersed, perhaps, but still containing liquid.

There is a method, which was used to a considerable extent in Germany in the 1940s, but is now infrequently used. That method was to apply a dry, finely dispersed coating on the inside of the spinning mold. With the mold continuing to spin, the molten metal was introduced into the mold to form the casting. This method was used quite successfully, but did not provide a very good or uniform outside diameter of the casting.

Wet slurries or washes, which are sprayed on the inside diameter of molds, have been refined to such an extent that they have become very popular and are widely used in all types of centrifugal casting foundries.

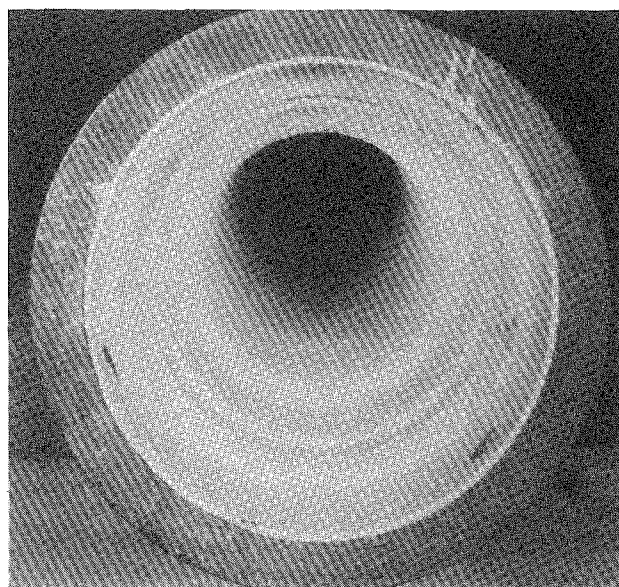


Fig. 6-6. This is the appearance of a soil pipe mold with the mold coating properly applied.

Mold Heating and Cooling

HEATING

When producing centrifugal castings in a permanent mold it is desirable to maintain the mold at the temperature most suitable for the production of the castings. Actually, of course, it is impossible to maintain the mold at a very low temperature because each time a casting is made a very appreciable amount of heat is released from the molten metal into the mold; heat which must then be removed. If the production rate at which the castings are being produced is very high, the mold will normally operate at a temperature much elevated from room temperature. (The subject of mold heating and cooling is also covered in Chapter 4: Molds.)

Most mold coatings, which are applied to the inside diameter of the mold, require that the mold be at some elevated temperature in order to dry the mold coating material. The vehicle contained in most coatings is water, although sometimes a mixture of water and alcohol is used. In order for the coating to properly dry, the minimum operating temperature for the mold should be something in excess of 250F/121C. In a high-production machine the mold temperatures generally range from 400 to 500F/204 to 260C. For some types of castings it is desirable to operate the mold at temperatures of from 600 to 800F/316 to 427C.

In some plants the practice is to pour an initial casting and leave it in the mold for some time to pre-heat the mold to the normal operating temperature. Since the mold should be hot when the coating is applied, it is necessary that the mold be stored or left from the previous day with the mold coating already applied on the inside diameter. This method is quite satisfactory for some mold coatings, but others might tend to flake off. The result is that when the metal is poured into the relatively cold mold, it could cause the coating on the inside diameter of the mold to erode. This would cause difficulty in the extraction of the casting, and even cause damage to the mold itself when attempting to remove the casting.

In general, the molds are pre-heated before production begins by placing a mold in a core oven, which will bring the mold up to the operating temperature before it is placed in the casting machine. In other cases the molds are pre-heated on the casting machine by applying either gas or electrical heating to the mold while it is slowly rotating, thus bringing it uniformly up to temperature (Fig. 7-1a,b,c).

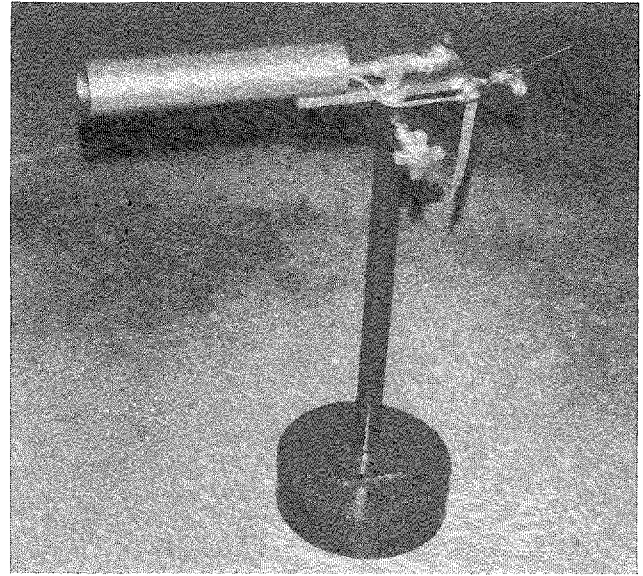


Fig. 7-1a. Mold heating torch for small size horizontal machine.

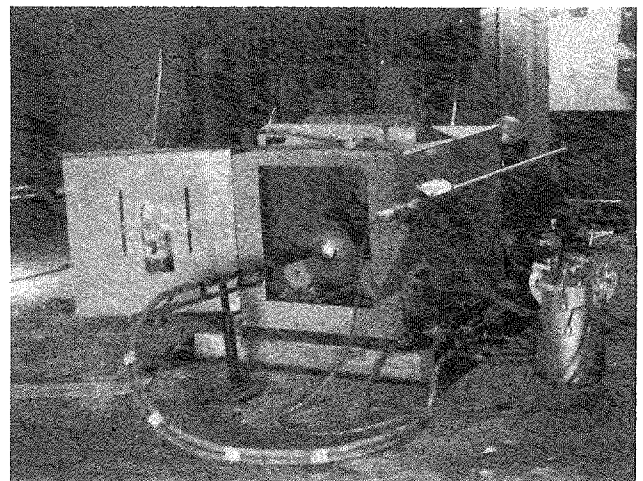


Fig. 7-1b. Mold heating.

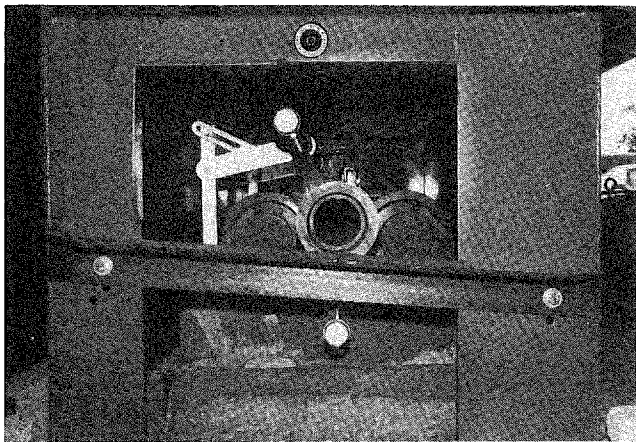


Fig. 7-1c. Mold heating.

It is not recommended that oil heat be used. Oil burners sometimes spit oil because of their incomplete combustion, and the result is that some oil could accidentally get into the inside of the mold. This would be very detrimental to the process of the mold coating adhering to the mold and would cause difficulty or actual damage to the mold. After the molds are pre-heated, they are put into service by spraying the mold coating on the inside diameter in the usual manner.

When a machine is shut down for the lunch hour, a change of shift, lack of metal, or for any other reason, it is good practice to keep the mold slowly rotating and apply just sufficient heat to maintain the mold at its operating temperature.

COOLING

If the molds are not cooled by some means they will gradually attain higher and higher temperatures, depending upon the rate of production. Air cooling of molds is very inefficient and is only used for very low production rates. Many different methods have been attempted to utilize air cooling, such as blowing jets of air at the mold or putting fins on the outside of the mold to increase the surface area. All of this has been for naught, as comparatively little heat is lost from the mold by air cooling.

Water cooling of molds is very efficient and can permit very high production rates (Fig. 7-2). Some machines are designed so that the molds are completely enclosed in a water box. The mold rotates but the water box does not. In this design, the mold can be pre-heated by circulating hot water around it before the initiation of operation. This is a very usual method for controlling the temperature of the molds in the De Lavaud pipe casting process (Chapter 16: De Lavaud Process). However, these machines are only used for the production of cast iron and ductile iron pressure pipe and cast iron soil pipe.

Practically all other types of centrifugal casting machines utilize jets of water to impinge upon the outside diameter of the mold. This method is quite efficient in removing the heat from the mold as well as maintaining a desired temper-

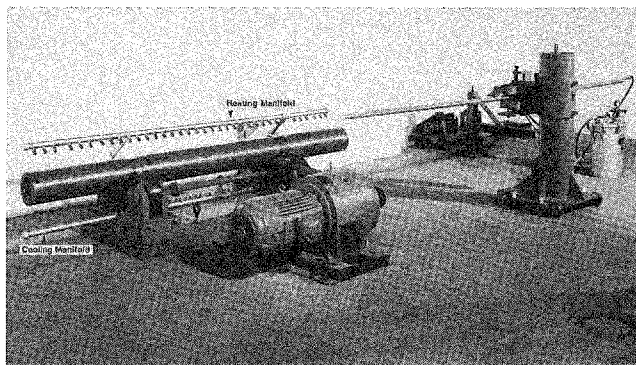


Fig. 7-2. Mold heating and cooling.

ature of the mold. The usual practice for utilizing the jet water cooling method is to either automatically or manually turn the water jets on immediately after the completion of the pouring operation. The water can then be left on and later be turned off automatically, by means of a timer, if desired.

Naturally, during the casting period the mold will absorb heat from the molten metal, thus raising the temperature of the mold. The water cooling extracts heat from the mold so that the two can be balanced to maintain an overall average temperature. It must be kept in mind that, while the mold will rise in temperature after the metal has been poured there, it will decrease below the average operating temperature if the water is left on for too long a time.

Attempts have been made to automatically control the length of time that the water should be left on to properly maintain the temperature of the mold. However, these attempts were met with many difficulties. For instance, if a radiation pyrometer is used to read the outside mold temperature, it will show completely different readings, depending upon whether the water is turned on or off. Therefore, the system that becomes practical would be one that reads the temperature of the mold immediately after the casting has been withdrawn. The system would then determine the length of time the water should remain on during the ensuing period. For example, if the temperature of the mold is somewhat higher than desired, the reading at this point in the cycle would be higher and, therefore, more water would be called for. Subsequently, during the next cast the temperature would result in a somewhat lower reading.

This water jet cooling system can also be used to control the lengthwise temperature of the mold. In the case of a very long mold, it will be found that the temperature is not uniform along its length. This means that some adjustment to the system must be made so that the mold will be more or less uniform in temperature throughout its length. Normally, this is done by controlling the number of jets by turning some of them off or turning them down until a uniform temperature is obtained.

While it is possible to do all of this automatically, it has been found in practice that the cost is quite high. It is quite easy to manually adjust these jets and the length of time the water impinges upon the mold for a particular type of production.

Rotational Speeds

GRAVITY

When discussing rotational speeds, it is usual practice to talk in terms of "G"s, or the number of times gravity that the casting is spun. Thus, when producing a casting of relatively small diameter, if it is spun at an RPM equivalent to 60G, the forces being exerted on that casting will be the same as that of a large diameter casting being spun at a speed equivalent to the same number of Gs on the inside diameter. As far as the metal is concerned, even though the RPM of the casting is different, the centrifugal force on the metal itself will be the same for the smaller inside diameter castings as that for the larger inside diameter castings.

The curve sheets shown in Figure 8-1 permit very easy determination of the proper RPM at a particular G for castings of many different inside diameters.

On vertical centrifugal casting machines we usually want to produce a casting with little or no taper on the inside diameter, a practical speed of rotation for the casting is 75G, based on the inside diameter of the casting being made. This will result in a taper that is not normally apparent to the eye, and results in little or no difference in the amount of machining required to produce a true cylinder on the inside diameter and outside diameter.

When making a bushing, it is generally the rule to produce the bushing in a horizontal centrifugal casting machine. However, if the bushing is relatively short in length, with respect to the inside diameter, it can readily be produced in a vertical centrifugal casting machine. From a practical standpoint, a casting whose length is more than two times the inside diameter is considered most suitable for horizontal centrifugal casting.

Theoretically, it should be possible to produce a true cylinder on the inside diameter of a horizontal centrifugal casting when rotating at extremely low G-forces. However, as a practical matter, it doesn't quite work out that way. This is due to the fact that the molten metal has to be accelerated up to the spinning speed of the mold before the casting has a chance to solidify. It is also important that the metal not slip on itself during its solidification period, as this could result in a defective casting.

There are certain practical criteria to be noted as to the spinning speed. The conductivity and temperature of a mold

can speed or retard solidification. Their effect on spinning speed is similar to that of the "life" (rate of solidification) and temperature of the metal. With cold, high-conductivity molds, the requirements for excess speed are increased if longitudinal flow is the determining factor and decreased if the factor of acceleration is the more important. The surface of the mold must entrain the first metal poured against it, and should not be polished to the extent that slippage occurs.

The lowest normal spinning speed that would be used for producing horizontal centrifugal castings in a tubular shape could be as low as 20G. Usually tubular castings, such as pipes or tubes, are cast at rotational speeds of 40–60G on their inside diameters. In some cases the high alloy, sluggish types of metals, which are quite viscous, are cast at speeds in excess of 100G.

In the case of producing castings with very heavy wall sections (10 in./254mm or more), the above criteria must be used with caution. The inside diameter then becomes quite small. If the usual criteria of, let's say, 60G were used on the inside diameter, it would result in a rather excessive speed of rotation. This could produce excessive tensile stresses in the outside diameter of the casting with the result that longitudinal cracks could result. Furthermore, very high rotational speeds, and therefore forces, would be exerted on the mold itself so that the hoop stress in the mold could become excessive and cause the mold itself to fail. Lower speeds of rotation tend to reduce longitudinal cracks in the casting, as well as the high stresses in the mold itself. When very heavy wall section castings are made, certain conditions for pouring exist, which are discussed in Chapter 11: Special Castings.

DETERMINING ROTATIONAL SPEED

Since the weight and radius of rotation are determined by casting dimensions, spinning speed is the only variable for the action of centrifugal force.

Because gravity acts with a constant magnitude and in a vertical direction, any change in the combined action of these two forces must come through changing one of two things: either the angle of the spinning axis to the horizontal or the speed of the spin.

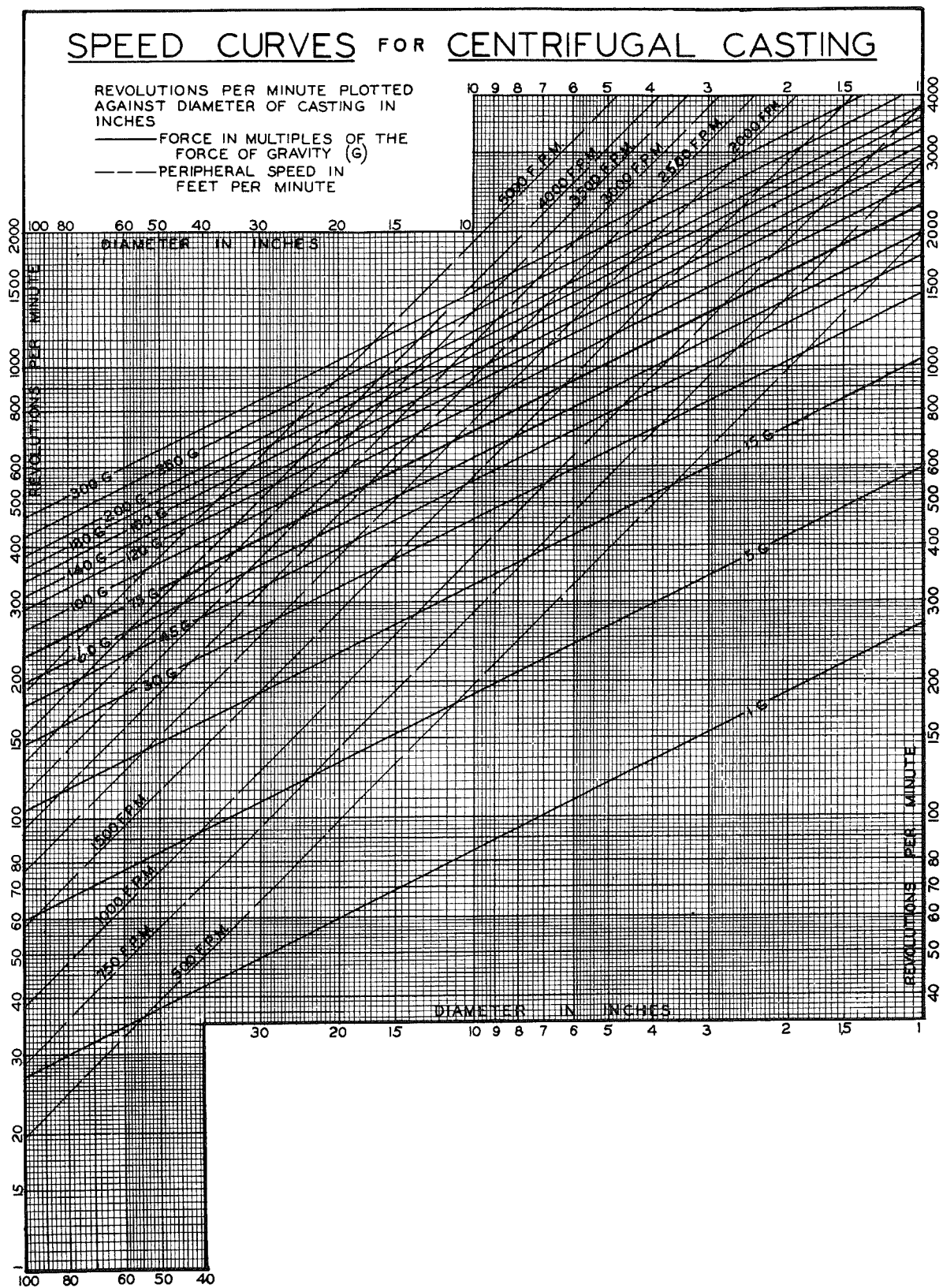


Fig. 8-1. Speed curves.

The position of the spinning axis in casting machines is usually chosen to fit in with the type of casting being made. If the axis angle is kept constant during the casting operation, the spinning speed can be used to control the effects given to the metal by the combined forces.

As a practical matter, most centrifugal castings are made in either a vertical or horizontal axis machine. The use of an inclined axis is of minimal practical use. Only a very small percentage of centrifugal castings are made in an inclined axis machine.

Vertical Axis

Pouring rate for a vertical axis machine is limited by the amount of metal that can be accelerated continuously, and the pouring temperature has upper limits to meet other conditions. Therefore, higher spinning speeds are sometimes required to hasten the flow. This is true both for molds poured against the side wall and for molds poured against the end (bottom). However, the relationship of spinning speed to rate of flow is somewhat different, depending on whether the mold position requires the metal be poured on the bottom or on the side wall. Because of the difference produced by the two areas of pouring, the factors determining the casting speed are considered separately for each.

In general, the mold is rotated at such a speed as to create a centrifugal force of the order of 60–75 times gravity at the inside diameter of the casting.

Such a condition of spinning speed has generally been found to be optimum for rapid pickup and distribution of the molten metal, and for holding the molten metal in place during solidification under sufficient pressure to ensure a well-fed metal section.

Metal Pickup

When molten metal is poured onto the surface of a rotating true centrifugal casting mold, all of it is not picked up (accelerated) immediately. Rotational velocity is imparted to it by virtue of the friction between the liquid metal and the mold. After the inner mold surface is covered, all succeeding metal will be accelerated by reason of internal friction between the liquid surface already spinning and the metal to be picked up. This creates an appreciable tendency to slippage.

An increase in mold speed above that which allows slipping and cascading (raining), but below the critical vibration range, tends to reduce the metal grain size. Also, inner surface quality improves as spinning speed increases.

With the optimum spinning speed the metal will be picked up rapidly and held firmly to the mold wall without slipping or raining. With the liquid metal in place, a pressure gradient is established radially across the wall thickness of the casting as a result of the centrifugal force, which is effective in cleansing the metal of nonmetallic inclusions. This pressure is lowest at the inner surface, increasing to a maximum at the outside of the casting. Since particles of different densities are subject to different pressures at a given rotational velocity, there is a tendency to an outward movement of the higher-density material, displacing the lower-density material toward the inner casting surface. In this manner

small slag particles and other light nonmetallic inclusions are separated out toward the inner surface, to be removed by a subsequent machining operation.

Metal Flow and Mold Speed in Horizontal True Centrifugal Casting

The spinning speed used in casting with vertical or steeply inclined molds is usually fairly close to the calculated minimum speed for the cavity. Conversely, with horizontal or slightly inclined molds a wide difference exists between the casting and minimum speeds. This is due to the fact that in molds with the more flat spinning axes, the metal is delivered against the mold circumference. On the other hand, the metal striking the mold surface during the first revolution will be picked up by mold surface friction and all succeeding metal will be accelerated by reason of the velocity of the liquid surface already spinning and the viscosity of the metal itself. Outward force increases as the metal moves away from the neutral axis. This creates an appreciable slippage in the liquid strata between the mold and the interior surface, which must be compensated for by increasing the mold speed to increase centrifugal force.

In horizontal molds, cavities are cylindrical and there is a definite spinning speed for each cavity radius below which the centrifugal force cannot prevent the metal from falling as it spins through its upper arc. This establishes a minimum spinning speed to which the metal forming the inner surface must be accelerated. With this higher spinning speed for the surface, the metal will be held in place. Therefore, the current mold spinning speed must be adjusted to give this acceleration.

READING MACHINE RPM

When vertical centrifugal casting machines or horizontal face-plate type machines are used, the speed of rotation can usually be read on the machine's tachometer. Even though a v-belt drive might be used between the drive unit and the spinner shaft, the tachometer can be calibrated for the sheave ratio to obtain a reading of the rotational speed.

In the case of the horizontal trunnion machines, which are very popular and widely used for the production of horizontal centrifugal castings, it is not quite so simple. In this type of machine, where molds ride on the trunnions, a v-belt drive is generally used between the driving unit and the trunnion shafts. The trunnions for a particular machine would be of one particular diameter. A reduction in RPM results from the speed of the driving unit to the speed of the trunnion wheels, because of the v-belt drive or other type similar drive. There is also a further change in RPM determined by the diameter of the trunnion wheels and the diameter of the mold itself.

For example, if the v-belt drive has a reduction of 2-to-1, and if an electric motor is used with an output speed of 1800 RPM, the speed of the trunnion shaft will be 900 RPM.

MOLD SPEED VS DRIVE SPEED CURVE

MODEL M-12-12-AM S/N J-6527

DRIVE SHEAVE 5.30"

MACHINE SHEAVE 3.35"

TRUNNION WHEEL SIZE 8"

DRIVE OUTPUT 1225/225 RPM

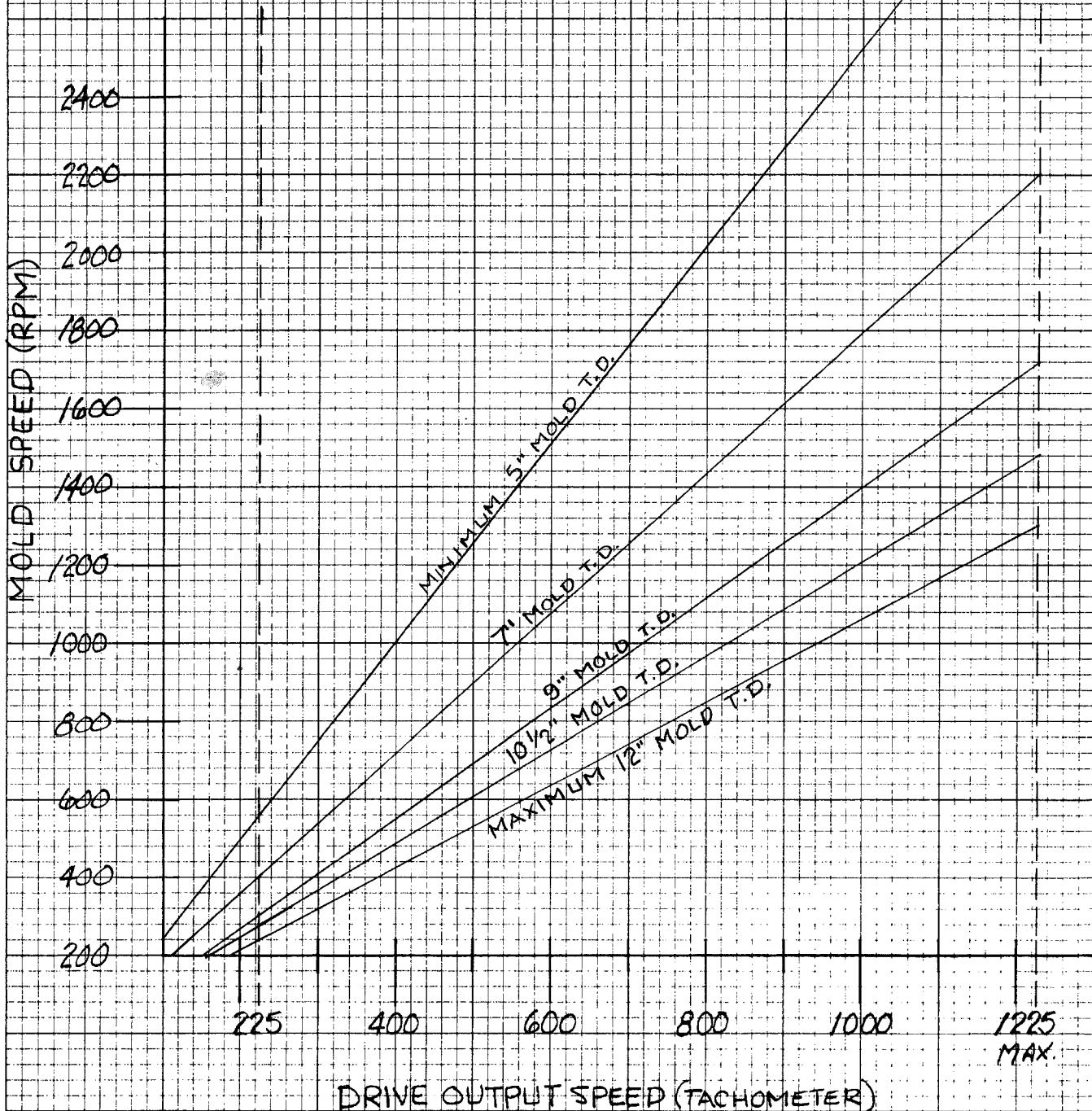


Fig. 8-2. Mold speed versus drive speed curve.

If the diameter of the trunnion wheel is 12 in. (51 mm) and the diameter of the mold, where it rides on the trunnion wheels (track diameter), is also 12 in. (51 mm), then the mold will actually be running at the same rotational speed as the trunnion wheels, which in this particular case is 900 RPM. However, if the mold has a track diameter of 18 in. (457 mm) and the trunnions are rotating at 900 RPM, the mold will rotate at only 600 RPM. For this reason, it is not practical to have the tachometer read the mold rotational speed directly, since each different size (diameter) of mold placed in the machine would be rotating at a different RPM, depending upon the diameter of the particular mold. To overcome this difficulty, speed curves are usually furnished with the casting machines, so that the operator can select the proper RPM of the output for the drive to suit the desired RPM for any one particular mold (Fig. 8-2).

Tachometers

In general, there are three different types of tachometers used on centrifugal casting machines. The first type is called a mechanical tachometer. It is generally used in automobiles and is quite satisfactory. A long flexible cable is required between the point of reading the speed and the dial indicator for the tachometer. Even though these will last quite some time, eventually the cable or some part of the mechanical system will fail and require replacement.

The second type of tachometer is one that is ordinarily called an electrical tachometer. In this case, a tachometer pick-up head is used, which is driven by the machine at some point, and is actually a small electric generator. This generates a voltage that is carried by wire to the reading point, which is actually a high-resistance voltmeter. Thus, the RPM read is proportional to the voltage, which is proportional to the speed of rotation.

A third type of tachometer, which is electronic, utilizes a sprocket or gear with a given number of teeth on it. This sprocket or gear is installed on the shaft of which the speed is to be measured. A magnetic pick-up, located a very few thousandths of an inch from the gear, reads the number of "pips" or teeth that pass that point. This information is carried to a small electronic box, which converts the number of pips into revolutions per minute, or whatever unit is desired. These very satisfactory units are usually used with hydraulic drives, as they are most easily attached to the point at which the speed is to be read.

INFLUENCE OF ROTATIONAL SPEED

There are a number of factors influenced by rotational speed:

- rate of metal pickup and flow along length of mold;
- structural uniformity and structural character of the solidified metal;
- extent of chilling action of the mold on the layer of metal immediately in contact with mold surface;
- pressure on mold surfaces;
- pressure gradient across the casting wall;
- circumferential tension in casting wall.

Slower pouring may compensate to some extent for an increased pouring temperature, since it enables acceleration to be brought about more effectively. In other words, the minimum spinning speed for satisfactory castings will be lower when using a slow pouring rate or a low metal casting temperature than when using faster pouring or hotter metal.

TAPER (Vertical Axis)

Sometimes it is necessary to produce a casting with taper on the inside diameter. In such a case, it is possible to calculate the speed of rotation and, thus, produce a casting with the desired taper. The actual conformation of the inside of a casting made in a vertical machine is a parabola of revolution. However, in practice, the speeds of rotation are much higher and only the essentially straight portion of the inside diameter is in the centrifugal casting. The apex of the paraboloid of revolution is many feet below the bottom of the mold. In this way, it is possible to centrifugally cast a tapered inside diameter (i.e., a bushing) as a true centrifugal casting when it is made in a vertical machine. The formula for calculating the speed for a particular taper is as follows:

$$N = 264 \sqrt{(1/(r_1^2 - r_2^2))} \sqrt{H}$$

where

- N = RPM
- r_1 = Inside radius at top of bushing in inches
- r_2 = Inside radius at bottom of bushing (in inches)
- H = Height of bushing (in inches)

As an example of this type of calculation (Figs. 8-3 and 8-4), it is desired to calculate the proper rotational speed to centrifugally cast a cylinder having an inside diameter of 8 in. at the top and 7¼ in. at the bottom, with a height of 8 in. From the above formula, the calculated speed (N) would be 744 RPM, or equivalent to a peripheral velocity of 1500 ft/min.

It has been found in actual practice that the amount of taper on the inside diameter of the casting cannot be materially reduced by rotating at speeds over 1500 ft/min, peripheral velocity.

Therefore, to produce a casting that is actually conical in shape on the inside diameter, it is merely necessary to calculate the volume of the casting and the speed of rotation. Thus, the desired end product can be produced with minimum machining (Fig. 8-5).

A conical inside diameter casting is most unusual. It is more common to produce castings with definite-to-little or no taper on the inside diameter. The formula given may be applied directly to calculate the RPM necessary for the production of a particular taper on the inside diameter.

It should be noted that the equation is independent of the type of metal that is being poured, whether it be aluminum, cast iron, steel, or otherwise.

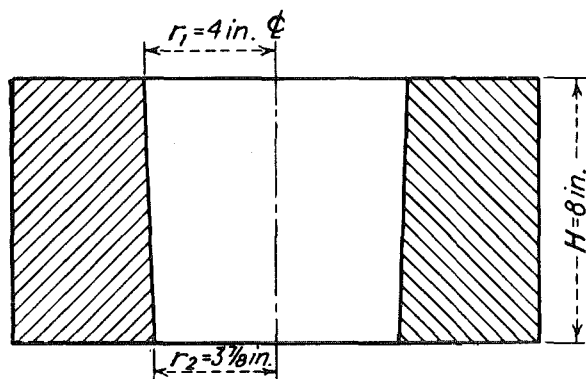
CASTING DIMENSIONS

Casting thickness has no effect on calculations for minimum spinning speed. Very thin castings require a rapid longitudinal flow to spread the thin sheet of metal over the mold surface before it solidifies, and a higher speed is required than is for thicker castings. For accelerating the metal, slippage is more pronounced with a deeper layer of molten metal and the mold spinning speed should be higher.

The length of the casting increases the time required for longitudinal flow and a smaller cavity radius not only increases the minimum spinning speed but shortens the arc length in which the acceleration must take place. As a result, the speed required above the minimum must be greater for longer castings (if quickly solidifying metal is used), and the ratio of casting speed to the minimum must be increased as the cavity radius becomes smaller.

MACHINE CONSTRUCTION

In designing the casting machine, consideration must be given to such details as the removal of the castings from the mold and whether pouring from a ladle directly into a mold on a high-speed vertical casting machine compensates for the difficulties with spouts and troughs on horizontal casting machines.



$$N = \left(264 \sqrt{\frac{1}{r_1^2 - r_2^2}} \right) \left(\sqrt{H} \right)$$

Where N = r.p.m., r_1 = inside radius at top in inches, r_2 = inside radius at bottom in inches, and H = height in inches.

Fig. 8-3. To centrifugally cast a cylinder with a taper of the dimensions shown here would require a peripheral speed of about 1500 ft/min, according to the formula discussed in this chapter.

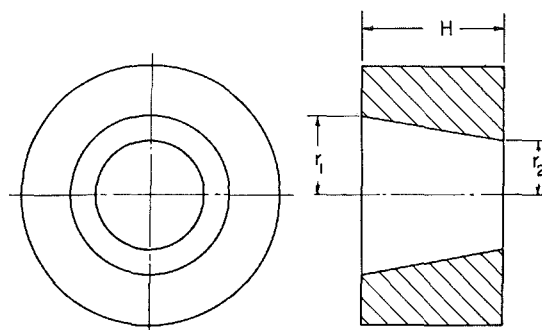
The design of the trough or spout must also depend on the fluidity of the metal and diameter of the mold cavity, as well as the stream shape when it impinges upon the mold surface. Therefore, the design of the casting machine can be changed to give lower spinning speed only when general operating conditions permit.

VIBRATION

Regardless of the other details, vibration will materially increase the spinning speed required for accelerating the metal. This is due to the metal being entrained by surface contact and, if this contact is made intermittent by vibration, the accelerating force cannot be smoothly applied. This is evident—especially in horizontal casting machines—when the spinning speed enters the vibration range of the machine. Then, increasing the spinning speed will also increase vibration and the metal can continue to fall as it passes through the upper arc, in spite of the increased speed. Vibration has a much greater effect in horizontal casting machines than it does in vertical casting machines. This is due to the greater relative importance of acceleration, and the quality of metal poured.

Other relevant factors in speed selection are the mechanical capabilities of the equipment and the hoop stresses generated in the solidifying casting, which govern the maximum permissible operating speed.

You can produce castings with a taper on the inside diameter in a vertical centrifugal casting machine by controlling the speed of rotation. Here is the formula:



$$N = 264 \sqrt{\frac{H}{r_1^2 - r_2^2}}$$

N = rpm

r_1 = inside radius at top of bushing in inches
 r_2 = inside radius at bottom of bushing in inches
 H = height of bushing in inches

Fig. 8-4. Determining rotational speed for castings with taper on inside dimension.

Although centrifugal forces exceeding 200G are utilized in some cases, most practice is empirically based within the range of 10–150G. The highest values are used for open-bore cylindrical components of small diameter and the lowest for semi-centrifugal and centrifuging. Speeds generating forces of 60–80G are most commonly quoted for true centrifugal castings. As previously emphasized, however, the optimum value of centrifugal force diminishes with increasing diameter.

METAL EFFECT

The metallurgical characteristics that influence the determination of spinning speed are the rapidity of solidification of the metal and the temperature above that metal's solidification point. To avoid cold shuts, the metal must be spread over the entire mold length in one continuous flow, similar to the flow across an open sand mold. With quickly solidifying metals, either because of lack of fluidity or low temperature, the pouring rate and spinning speed must be increased, correspondingly.

In practice, it is always necessary to use a mold rotational speed considerably in excess of that which gives a force of one gravity. This is because of the slippage occurring between the freshly introduced molten metal and either the rotating mold surface or the previously deposited layer of metal. At the critical moment, when the newly introduced molten metal passes over top dead center for the first time, it moves at only a fraction of the full speed. It is not until later that inertia is overcome and the metal is accelerated to mold speed.

The degree to which slipping occurs is a function of friction at the contacting surface. Friction increases with surface roughness, liquid metal viscosity, and those factors that speed up solidification, such as low metal and mold temperatures and high rates of heat extraction.

Once the initial layer of metal has been picked up at the mold surface, it is necessary to accelerate all the following metal to above 1G, before it also passes top dead center. This adds a dependence on pouring rate—the quicker the metal is introduced into the mold, the greater will be the speed required to hold it there. The effect is twofold: 1) increased inertia from more mass to be accelerated per unit time, and 2) decreased friction resulting from the deeper liquid bath.

This variability of the conditions existing in the casting process is the reason why it is not possible to calculate absolute spinning speeds and explains why, in so many cases, casting criteria is set by intelligent guesswork. The practical use of speed graphs lies in their ability to extend the range of experience from known sizes to the new job being cast for the first time. This is possible due to the range of operating conditions being rather limited in any one shop.

Two schools of thought exist with regard to the mathematical basis for relating spinning speed to casting diameter. In one case it is argued that since we are concerned with opposing gravitational force in order to hold the metal in the mold, the centrifugal force relationship should be used. Alternatively, it is suggested that because friction plays such

an important part in pick-up, mold rotation should be expressed in terms of peripheral velocity at the mold surface. Either method will give satisfactory results when the diameter and sections of the castings being compared are similar. However, trouble can occur when experience gained in one size range is used to predict spinning speed for a totally different class of work. This is because the amount of slip varies with the diameter and influences the effectiveness of mold rotation in picking up and distributing liquid metal.

Slip decreases as diameter increases so that mold rotation at 16 in. (406 mm) diameter appears to be twice as effective as mold rotation at 2 in. (51 mm) diameter. This conclusion is based on practically determined minimum speeds that will retain the metal in the mold. It is also based on the assumption that such speeds develop a centrifugal force equal to that of gravity at top dead center, when the newly introduced liquid metal passes over for the first time.

In practice, it is found that if mold speeds are calculated on the basis of a constant centrifugal force (for instance, x G) and extrapolated to larger diameters, or if they are determined from a constant peripheral speed and extrapolated to smaller diameters, there will be a tendency to use a higher spinning speed than is absolutely necessary.

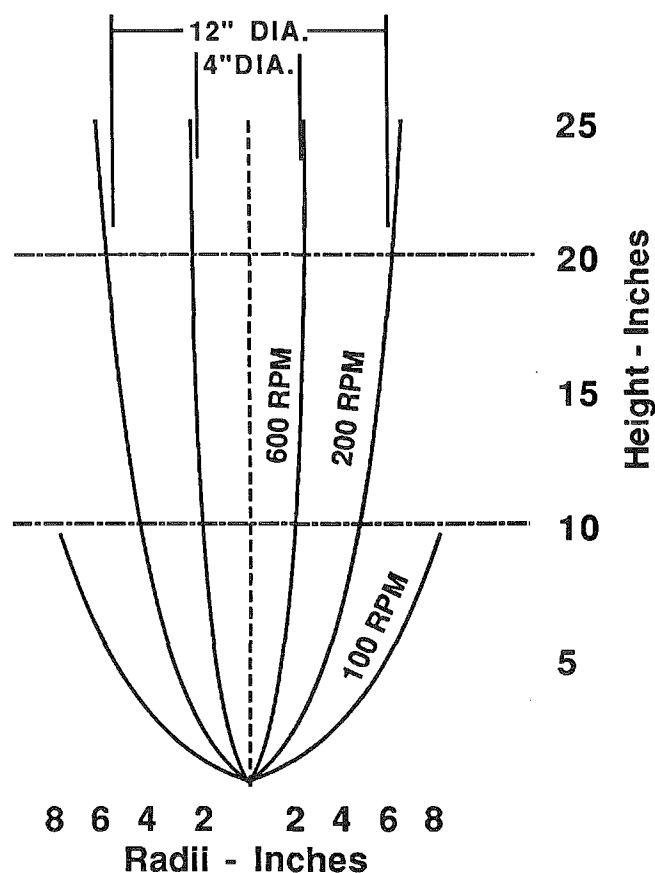


Fig. 8-5. Speed of rotation for castings with conical inside dimension.

Extrapolating in the opposite directions can be a far more serious matter since it is likely to give lower relative speeds than necessary, which may fail to retain the metal in the mold. Fortunately, there is usually ample latitude in permissible rotational speeds between the minimum for effective pickup and the maximum dictated by the need to avoid hot tears or machine vibration, thus giving a wide range in which high quality castings can be made of most alloys.

It is often found, with castings whose internal diameter is only a fraction of the external diameter, that the speeds necessary to hold the bore result in very high hoop stresses being set up in the initially solidified external shell. This can result in longitudinal hot tears. Low pouring rates and metal temperatures, together with hot molds, all help, but one of the major factors is to keep the rotational speed as low as practicable. Sometimes it is desirable to start pouring with a low spinning speed so that the stresses are at a minimum during the early stages of solidification. Then, the speed can gradually be increased as the mold fills up, so that full speed will be attained towards the end of casting. With either the constant or increasing speed techniques, a suitably determined empirical relationship can be a most valuable guide to setting the proper speeds for avoiding hot tears and with minimum risk of metal dropping (raining).

The importance of spinning speed is generally over emphasized. The method of introduction of the molten metal into the mold is of considerably more importance. If it is

possible to introduce the molten metal into the spinning mold so as to have initial velocity in the direction of rotation, then the RPM can be reduced considerably to reduce mold coating erosion, slippage, laps, etc.

Steel seems to require about the same spinning speed as white cast iron for acceleration, but, because of the high temperature and quickness with which it solidifies, increased speeds are required to give longitudinal flow as mold length is increased.

In practice, variations in operating conditions can be met by adjusting the pouring rate and spinning speeds for mean conditions. The mold conductivity, machine construction, and casting dimensions will be constant during the heat and the principal variables will be the differences in metal temperature and analysis that are normal in a foundry.

While acceptable for casting quality, these normal changes in temperature and analysis may be sufficient to cause irregular metal thickness due to insufficient speed or cause surface defects that come from too high a spinning rate.

The rate of longitudinal flow along the mold wall may also require a higher mold spinning speed than that calculated as the minimum for the cavity. The conditions affecting this are very similar to those governing the pouring of a flat plate in an open sand mold. A plate of very short length can be poured easily with any metal or mold material, but, as it becomes longer or cooler, the front edge of the metal will begin to solidify before the mold is filled. Faster pouring or hotter metal is required to prevent this from happening.

Pouring

POURING TEMPERATURES

Although some emphasis has been placed on the importance of the actual pouring temperature, it is not the most important factor when producing a centrifugal casting. The speed of rotation (see Chapter 8: Rotational Speeds) and the technique of introducing molten metal into the spinning mold are of equal, if not greater, importance. Nevertheless, a few things regarding temperature should be mentioned here.

When pouring metal castings in permanent molds, either statically or centrifugally, in most cases the metal pouring temperatures are exactly the same. However, in a few cases it is necessary to pour centrifugal castings at a higher or lower temperature than that used for static casting. Because of the fact that the mold is spinning during the centrifugal casting process, the molten metal is supplied with additional velocity over that which exists during the static casting process. The result is that the metal has more mobility and additional kinetic energy. At the same time, it is possible for the metal to become super-cooled when pouring into permanent molds. This accounts for the fact that centrifugal castings can, in many cases, be poured at lower metal temperatures than static castings.

Raining

Raining is harmful and can be caused by molten metal being poured at too high a temperature. It is very detrimental to the production of centrifugal castings, as it causes oxidation of the metal and is very likely to cause the formation of cold shuts, laps, or other types of similar defects on the outside diameter of the centrifugal tube.

Except in very specialized cases, such as the De Lavaud Process (Chapter 16), the metal is introduced at one end of the mold and caused to flow by centrifugal action throughout the mold length. If the spinning speed is adequate and if the fluidity of the molten metal is satisfactory, the metal will distribute itself uniformly in wall section throughout the mold before solidification.

If the temperature of the molten metal is too high or if the fluidity of the molten metal is too great, the metal will not readily accelerate to the speed of the mold. In a horizontally spinning mold, it will rotate around from the bottom

of the mold to the top of the mold, and since it may not have sufficient rotational velocity, the force of gravity will tend to make part of the metal fall from the top of the mold down into the body of the metal at the bottom of the mold. This phenomenon in centrifugal casting is called "raining" (Fig. 9-1).

If raining occurs, several correctional measures can be taken, depending on which effect is causing the raining. It is possible that the fluidity is too high, which could be caused by the metal being at an excessively high temperature. Therefore, reduction in the temperature of the metal would be advisable. The mold coating might be too smooth, in which case a rougher mold coating could be applied. This would permit the metal to gain velocity more readily because of the increased friction between the molten metal and the spinning mold. The speed of rotation could be increased, which would tend to assist the metal reaching a higher spinning speed more quickly because of the increased friction effect.

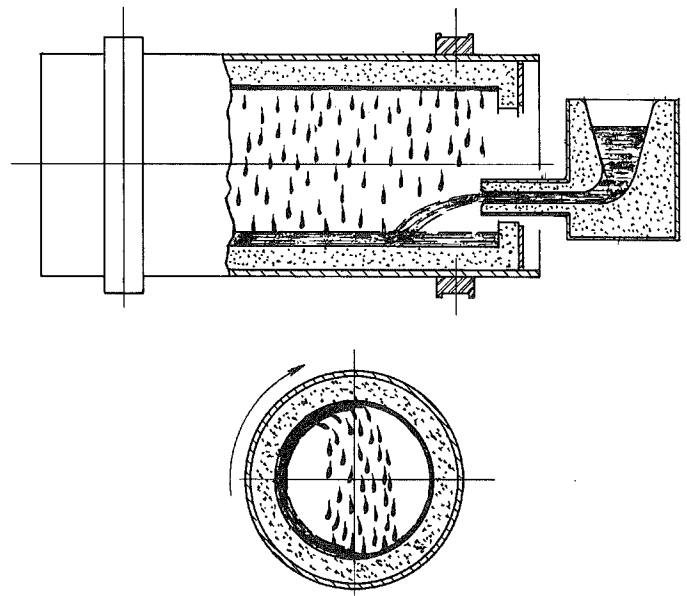


Fig. 9-1. Illustration of "raining" phenomenon.

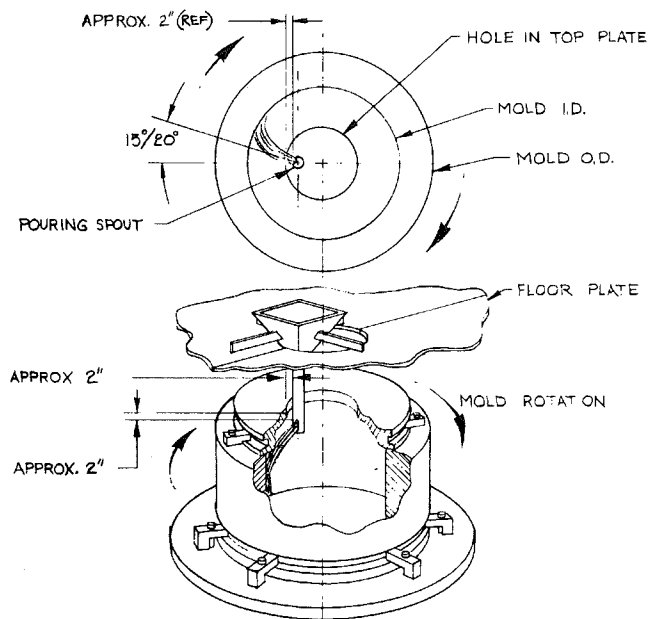


Fig. 9-2. Pouring spout position.

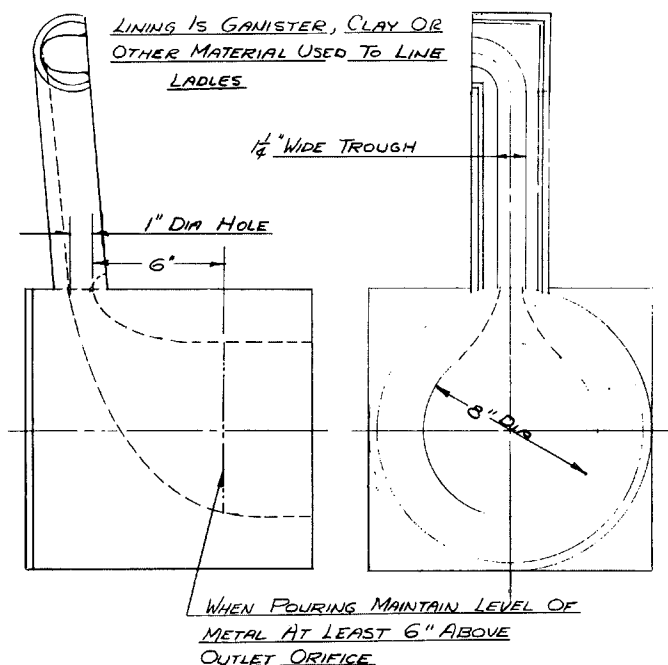


Fig. 9-3. Right-angle spout, runner pot lining.

POURING EQUIPMENT

When pouring into either a horizontally or vertically spinning mold, the metal should be introduced so that it has initial velocity in the direction of the mold's rotation (Figs. 9-2 and 9-3). This can be done fairly easily by utilizing a right-angle nozzle spout on the runner pot. The spout effectively diverts the flow of the molten metal from a direction in line with the axis of rotation to one at nearly 90 degrees to the axis of rotation. By utilizing this re-directed flow and the force of gravity, the flowing metal can be diverted to impinge upon the mold in a direction closer to that of the direction of rotation. Since the initial velocity of the molten metal is appreciable, it can more readily be accelerated to the spinning speed of the mold and, therefore, inhibit slip-page and mold erosion.

When the initial molten metal is introduced into the mold, it should enter the mold quickly and more or less as a mass in one location. The centrifugal force will drive the molten metal longitudinally, causing it to flow down the length of the mold and form a tube. When this occurs, there will be an absence of cold shuts and the metal will flow smoothly from the pouring end of the mold to the far end of the mold.

Straight Spout

If a straight spout pouring nozzle is used (Fig. 9-4), it is advantageous to have initial velocity of flow in the direction of the mold's rotation. In larger diameter castings, this can sometimes be done by inclining the runner pot to one side and elevating the spout in the mold. Any change that can be made in the introduction of the molten metal into the spinning mold, so as to have some initial velocity in the direction of rotation, is advantageous.

Boots

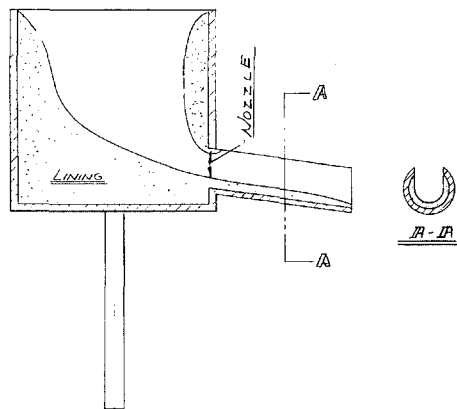
Cast iron castings, such as cylinder liners or pipe, are generally poured using cast iron "boots" (see Fig. 9-5). When boots are used, the rate of metal poured is totally determined by the operator or by a machine that tilts the ladle at a pre-controlled rate. These cast iron boots are generally sprayed or coated on the inside with a solution of graphite, after being pre-heated to approximately 300F/149C. This tends to prevent the molten iron from sticking to the boots, which protects them and prolongs their lives.

Properly designed and protected boots should last for thousands of castings. In some cases, the rate of casting production is so great that the boot, after some number of castings, becomes red hot. When this occurs, it is not detrimental to the boot to use a fine spray of water on the back side, after each cast, to reduce the temperature to a manageable level.

Other Types of Pouring Equipment

Some types of runner pots (Figs. 9-6 and 9-7) are made with refractory-lined steel pipe. Other types of runner pots use refractory materials for the main body of the runner pot and a ceramic pipe, runner tube or tile, protected on the outside by a steel tube or refractory. When very long spouts are required, the spout is generally hinged so that the

LINING MATERIAL IS GANISTER, CLAY,
OR OTHER MATERIAL USED TO LINE
LADLES



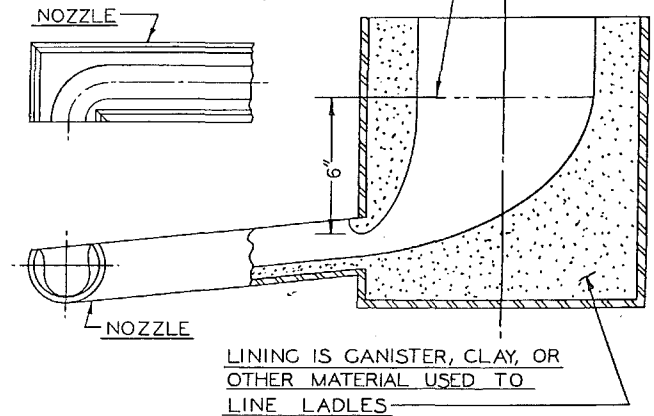
RUNNER POT

MOLD

NOZZLE

MOLTEN METAL

WHEN POURING MAINTAIN LEVEL OF METAL AT LEAST 6" ABOVE OUTLET ORIFICE.



NOTE
OPENING IN NOZZLE LINING
SHOULD BE SLIGHTLY SMALLER
THAN OPENING IN COVER

51

ceramic tile or refractory in it is quite easy to replace. When long spouts are used, they generally can be unbolted from the main body of the runner pot for ease in accessibility during maintenance and construction.

Runner pots should be pre-heated before the pour. In the use of refractory-lined runner pots, the pre-heat temperature should be very high, especially when steel is being poured.

Cast iron will generally leave an easily removable splinter or droplets in the runner pot. If the spout is then coated with graphite wash, it can be re-used immediately. Some types of runner pots, when used for steel or stainless steel, require very careful repair work after each pour and sometimes can be used for only one pour before requiring repair.

Runner pots used for jump-the-gap pouring fall into the above general classification. Those pouring iron can usually be re-used repeatedly, while those pouring steel can not. In this case, it is sometimes convenient to use a sand or refractory core for the runner pot spout, which can readily be replaced for each casting.

POURING RATES

Pouring rates for centrifugal castings (Fig. 9-8) are generally appreciably higher than those used in static casting. It is found that for heavy castings weighing 1000 lb or more, pouring rates from 100 to 200 lb of metal per second are successful.

In the case of small castings weighing 100 lb or less, a pouring rate of only 20 lb per second can be obtained. This is because it is practically impossible to have a higher pouring rate for such a small quantity of metal. A 100-lb casting should be poured in about 5 seconds.

Heavy-Wall Castings

For the production of very heavy-wall castings, it is necessary to use a somewhat different pouring technique. Heavy-wall castings are those in which the wall section thickness is in excess of $\frac{3}{4}$ –1½ in. (19–38.1 mm). If it were necessary to produce a 4-in. (101.6-mm) wall section casting, it could be assumed that if all the metal were poured into the spin-

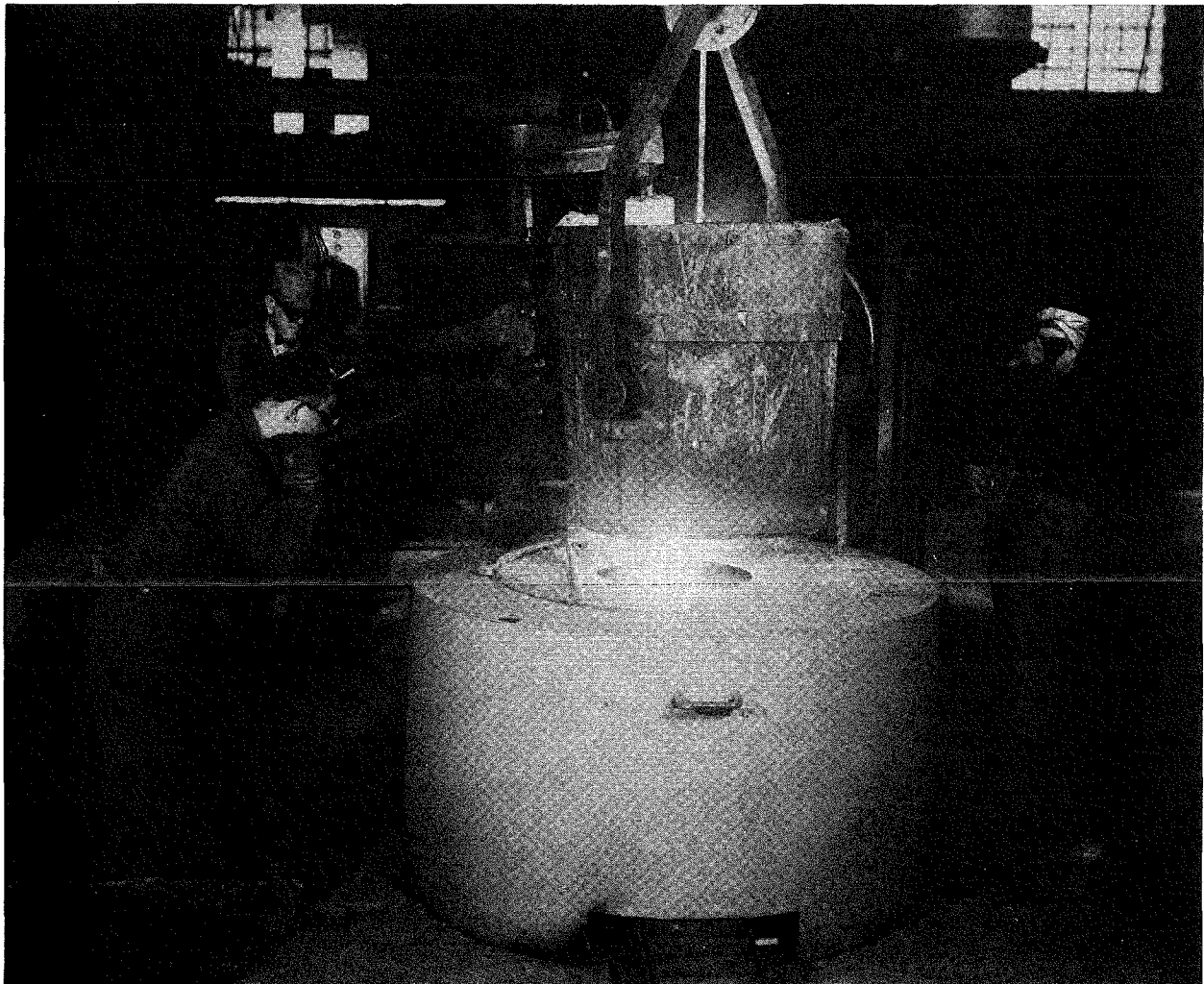


Fig. 9-8. Bottom-pour ladles are excellent for medium-to-large castings.

ning mold very, very quickly, the metal would certainly *not* be immediately accelerated to the speed of the spinning mold. It would slosh around in the mold and raining would occur, causing the usual detrimental effects. As a matter of fact, in very large, heavy castings, it not only would rain, but the metal could pour out of the opening in the end plates.

The technique used for pouring heavy-wall castings is as follows: The operator pours the initial 25% of the weight of the casting into the mold at the usual high pouring rate. He then slows the rate of pour into the spinning mold to a considerably lower rate. The effect of this technique produces an initial casting of approximately 1–1½ in. (25.4–38.1 mm) wall section, which permits the metal to accelerate to the spinning speed of the mold. The additional metal flowing into the mold enters at a lower rate. This enables the spinning mold and the friction of the casting against the viscous molten metal to accelerate the additional molten metal to the spinning speed of the mold. In this way, a smooth acceleration of the metal to the spinning speed results. It is highly desirable that minor turbulence of the metal exists. The metal should smoothly accelerate to the speed of the spinning mold.

This change in pouring rate can be accomplished in several ways. It is possible to do it manually when using an open type of runner pot so that the rate of pour is controlled by the operator. To do this, the operator first pours very quickly over the lip of the ladle into the runner pot and then slows down the rate of pour.

Another—and somewhat better—method of accomplishing this is to use a runner pot with a pre-designed size of nozzle opening. Here, the operator pours the metal very quickly into the runner pot, filling it to near the top. This puts a high head of metal on the runner pot nozzle and causes the metal to go into the mold at a relatively high rate of pour. The diameter of the nozzle, rather than the operator, determines the rate of flow. In this way there is less tendency for human error. After the initial 25% of the pour, the operator permits the level of the molten metal in the runner pot to decrease by reducing his rate of pour into the runner pot. The metal then enters the mold at a much slower rate. Since there is a lower head of metal on the runner pot, the rate of metal flow into the mold will be considerably reduced. This latter technique can be used equally well with over-the-lip pouring or bottom-pour types of ladles.

It is of the utmost importance that the stream of molten metal entering the mold never be interrupted. An interruption of the flow can cause various defects adjacent to the outside diameter, or even in the interior of the casting. These defects are usually in the nature of laps or discontinuities in the metal of the casting.

When pouring relatively large diameter castings, whether of heavy-wall section or not, it is desirable, as mentioned previously, to have a right-angle nozzle spout at the end of the runner pot so that the metal can be diverted. It is also usual to raise the elevation of the spout above the center

line of the mold so that the metal will have additional ability to arrive at the mold wall with initial velocity in the direction of the mold's rotation.

Small Inside Diameter Castings

There is always a problem when trying to produce castings that have small inside diameters. The difficulty lies in the restrictions in size of the the runner spout. Naturally, the diameter of the hole in the mold end plate, through which the spout must pass, must be somewhat smaller in diameter than the inside diameter of the casting that is going to be produced. Then, there must be clearance between the outside diameter of the runner spout and the inside diameter of the end plate hole, which further restricts the size of the runner spout. Additionally, the runner spout, usually made of steel, must be lined with either ganister or other refractory materials. The result is that there is a very, very small hole for the metal to go through.

One solution to this problem would be to utilize a refractory-only spout through which the molten metal could pass. However, these have never proven to be very satisfactory when used without a steel container to back up the refractory tube. The spout would be subject to the shock of the molten metal coming through it and could rupture or fail during the pouring operation. If the refractory tube or spout was inside a pipe it would be satisfactory, but that would necessarily require a larger outside diameter for the entire spout.

A better solution to the dilemma for small inside diameter castings is to use the "jump-the-gap" method of casting. In this method, the runner spout does not actually protrude through the end plate hole. It is merely placed immediately adjacent to the end plate hole, slightly elevated above center if possible. The rate of pour of the molten metal will cause a solid stream of metal to flow out of the end of the runner spout nozzle into the mold cavity with neither the molten metal nor the runner spout nozzle touching the inside diameter of the end plate. This method, in practice, works very well indeed. It must be kept in mind that the runner pot should be slightly tilted so that it will drain completely and quickly. At the termination of the pour a few droplets might run off the end of the runner spout nozzle and touch the spinning end plate. This metal is caught within the guard at that end, with no detrimental effect.

Castings with an inside diameter as small as ⅜ in. (9.525 mm) have actually been poured. However, it is not generally economical to pour a very small quantity of metal, whether it be for centrifugal or static casting. (In the case of static casting, it is possible to arrange quite a number of such small castings in the mold so that the actual pour is a relatively large amount of molten metal.)

When producing centrifugal castings, we are pouring only one casting at a time. Economically, it takes just as long, and just as much fuss to produce a very small casting as it does for a larger casting. As a rule of thumb, if a casting does not weigh at least 10 lb (4.55 kg), one should give some thought as to whether or not it is suitable for centrifugal casting.

TWO-SPEED POURING

The two-speed pouring technique can be used quite successfully for producing centrifugal castings with metals that have very poor fluidity. This technique can also be used quite successfully for producing long, tubular products with relatively thin walls.

Previously, we have been concerned with bringing the mold up to the spinning speed, then pouring the molten metal into the spinning mold. This is not the best method for producing centrifugal castings of very sluggish metals with poor fluidity, such as some types of stainless steels. In this case, it is necessary to elevate the temperature of the molten metal to an extremely high degree to obtain good fluidity (with the resultant oxidation of some of the constituents of the metal). The problem is that, even so, the fluidity of the metal can still be quite low. The problem can be solved using the two-speed pouring technique.

In the two-speed pouring technique, the method is to introduce the metal into the mold at a controlled rate throughout the entire pour. During the initial period the mold is rotated at a very slow speed—something less than 50 RPM. The speed of the molten metal flowing into the mold should be such that just as the first metal reaches the far end of the mold, the last metal comes out of the runner spout nozzle into the mold. Almost all the metal is now lying in the bottom of the mold. Because the rate of rotation

is very low, the molten metal is not accelerated to the velocity of the spinning mold, but uses the mold itself as a trough. The rotational speed of the mold is then accelerated very rapidly, which picks up the metal, causing it to form a tube.

During the time that the metal is lying in the bottom of the mold it has very little surface area contact with the mold. The surface of the molten metal, which is exposed to the cooling effects of the mold, is rather small as compared with the volume of the metal, and there is a low rate of heat loss; the metal remains fluid. When the rotational speed is accelerated, it should be done rapidly because of the tremendous tendency of the metal to lose heat and solidify when the increased surface area of the molten metal is exposed to the mold surface.

This method may seem to be very tricky; however, in practice it is quite a simple matter of pouring and then pushing a button to cause the drive motor to accelerate very quickly from the low speed to the high speed. When using the two-speed pouring technique, castings are generally produced in sizes of no more than 5 in. (127 mm) outside diameter. The Wk^2 (inertia) of these smaller molds are comparatively low, with the result that it is possible to accelerate such molds to maximum required speed in approximately 5–8 seconds. Usually, the size of the drive motor for two-speed pouring is approximately twice the horsepower that would be used for single-speed pouring.

Casting Removal

SAND MOLDS

Several different methods can be used for the removal of centrifugal castings produced in sand-lined molds. It is necessary to either pull the casting out of the mold and later remove the sand, or push the sand and casting completely out of the mold at the same time. On the larger diameters and longer castings, it is possible to pick up the entire flask with the casting in it, stand it on end, then lift the mold off the casting. Later, the sand can be broken up and removed from the flask.

In some cases, a hydraulic ram is used to push the casting out of the flask. The sand is then broken up and removed from the interior of the flask. In other cases, it is easier to use a hydraulic ram to push the sand and casting completely out of the flask. The sand will fall away from the casting merely by hitting it a few times with a hammer.

The method to be used is the one which fits into the foundry with regard to facilities and equipment available, as well as the rapidity of production, the size of the flasks and castings, etc.

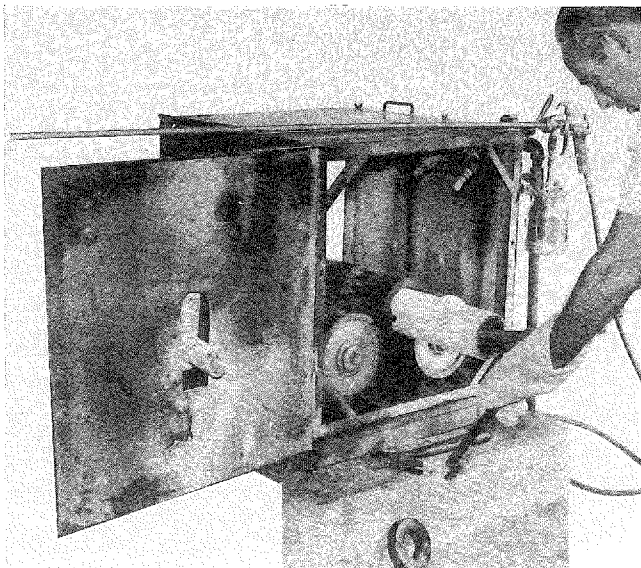


Fig. 10-1. After removing end plate, casting is easily removed with pulling tongs.

METAL MOLDS

Castings can be removed from metal molds by using a long bar with a flange at the far end. The bar is inserted into the bore of the casting, hooks onto the end, and pulls the casting out of the mold. In some cases, it may be necessary to use a hydraulic ram to force the casting out of the mold. However, this is only necessary if an incorrect type of mold coating is used that does not permit an easy release of the casting from the mold. Generally, the castings are very free and can be easily removed from the mold.

Various types of pulling tongs (Figs. 10-1 and 10-2) can be used for casting removal and can be operated either mechanically or pneumatically. These tongs are inserted into one end of the bore of the casting and clamped against the inside diameter of the pipe. This permits the pipe or tube to be readily removed from the mold. For the smaller sizes, the casting removal device is similar to a reverse ice tong, and can be used by an operator to pull the casting out of the mold very easily by hand. This casting removal device can also be used to carry the casting a short distance to put it in a tote box or into storage.

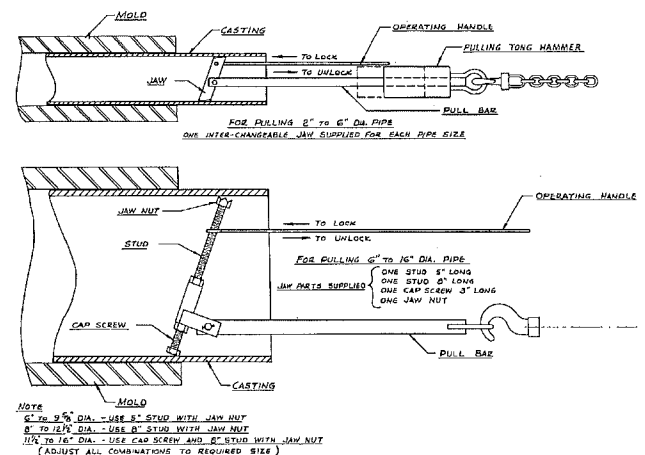


Fig. 10-2. Schematic drawing of pulling tongs.

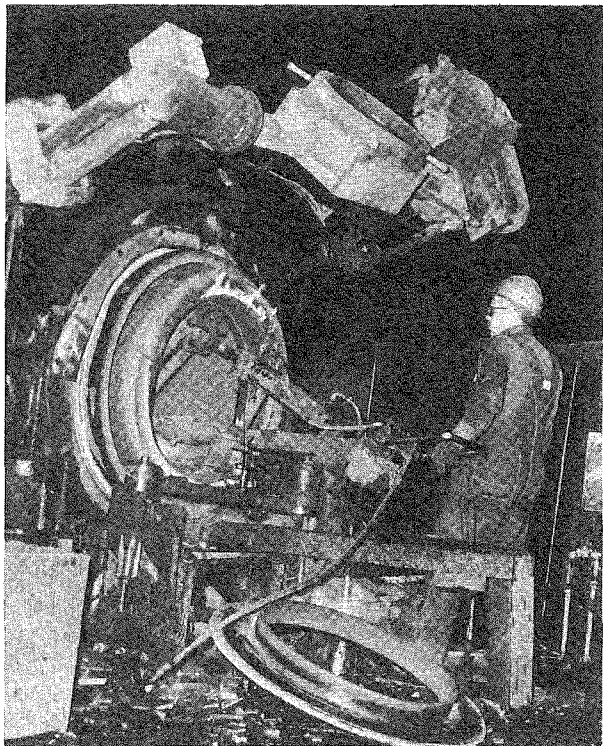


Fig. 10-3. A large, heavy hydraulically operated puller is necessary for removing large castings.

For pipe machines (Fig. 10-3) and cylinder liner machines, a hydraulic or pneumatic pulling device is generally used. This device engages on the inside diameter of the casting and automatically releases the casting after it has been pulled completely free of the mold. The teeth on these devices are usually coated with a hard coating material and are periodically re-surfaced and re-sharpened. It will be found in practice, however, that the pulling devices that operate on a wedging principle do not require very sharp teeth to exert very powerful pulling forces on the castings. If a casting cannot be removed from the mold with a pulling force of as much as 1000 lb, it is considered to be stuck in the mold. In the case of long, small-diameter, thin-wall castings, 8 ft (2.438 m) or more in length and less than 6 in. (152.4 mm) in diameter, it is possible to pull the casting out of the mold with no difficulty.

If the casting is merely placed outside of the mold to cool, it is possible for the casting to warp and thus not be a true cylinder. This is particularly true of certain types of thin-walled stainless steel or other steel castings. The remedy for this is merely to pull the casting out of the mold and put it on a set of trunnion wheels immediately (Fig. 10-4). The casting is rotated very slowly on the trunnion wheels so that the cooling will be uniform, with the result that the casting will be straight.

As the life of a permanent mold reaches its end, the castings will be progressively more difficult to remove from the mold because of the "checking" of the mold surface. When this occurs, the mold should, of course, be maintained by welding and re-grinding so that the mold surface remains smooth. Eventually, however, too much of the mold surface is checked and has many fissures in it, so that a casting cannot be removed. This is the time to discard the mold or re-bore it to a larger inside diameter.

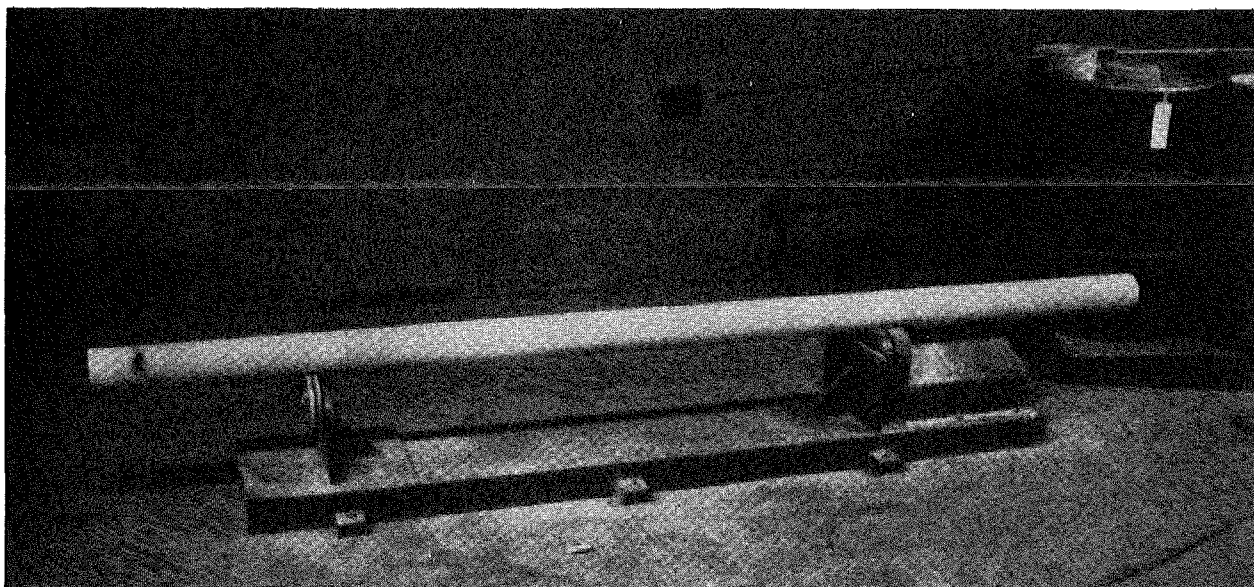


Fig. 10-4. Casting rotator.

Special Castings

BI-METALLIC CASTINGS

In certain specialized applications it may be necessary to conserve expensive metal, or to have a very hard, difficult-to-machine material on the outside of the casting and a soft, readily-machinable material on the inside of the cylindrical casting. This type of production is known as "bi-metallic" casting.

Generally, the first metal poured into the mold should have a higher solidification point than the second metal poured into the mold. However, metals with identical solidification temperatures can also be suitably cast. It is possible to centrifugally cast an outer diameter of stainless steel and an inner diameter of low-carbon steel, or vice versa.

The usual procedure is to bring two ladles of molten metal to the casting machine. The first metal is poured into the mold by the usual procedure for producing a cylindrical casting of the size and type and weight that it represents. Immediately after the molten metal is poured, the first ladle is removed from the vicinity of the machine and the second ladle of molten metal is placed in position, ready to pour. A delay time between the pouring of the first metal and the pouring of the second metal will generally range from 10 to 60 seconds. (In some cases a time delay in excess of 60 seconds is suitable, particularly for very heavy-wall castings.) The purpose of the delay time is to permit the first metal poured to solidify. The second metal is then poured into the mold, actually utilizing the first metal as a mold.

The perfection of the bond obtained by this method (Fig. 11-1) depends upon the relative cleanliness of the inside diameter of the first casting and its temperature. Usually there is enough "washing" (erosion) taking place by the second metal to cleanse or re-melt any slag on the inside diameter of the casting, so that it eventually ends up not at the interface, but at the inside diameter of the final bi-metallic casting. If the delay time between completion of the first pour and initiation of the second pour is too long, there will *not* be a perfect bond along the entire length of the casting, which would cause the completed casting to be rejected. If the delay time is too short, there will be too much washing (erosion) of the first casting by the molten metal of the second casting. As a result, the wall section of

the initial casting will be reduced, and there will be a very gradual gradation of the composition of the metal at the interface between the first casting and the second casting (Fig. 11-2).

Control of the temperatures and the delay time can give the operator the ability to control the amount of washing of the interface as well as the perfection of the bond. From a practical standpoint, the precision of the criteria is not very great. After a few trials, and after the operator has had some experience with bi-metallic casting, he can generally guess very closely what the suitable delay time should be as well as the temperature of the second metal.

Ultrasonic testing is usually a very suitable method for determining the perfection of a bond at the interface. Because of the increased cooling rate at each end of the casting as compared with the general length of the casting, any lack of bond will manifest itself at one or both ends of the casting. Thus, the lack of bond can usually be determined by visual inspection. Even though visual inspection might show that the casting is perfect, additional testing procedures should be used, especially in critical castings. It is possible that a relatively long length casting will have a lack of bond existing for 1 or 2 in. (25.4 or 50.8 mm) at either end or both ends of the casting, but will have a perfect bond throughout the length. In such a case, it could be economical to merely cut off the ends, with the result that the remaining casting has a perfect bond.

Many combinations of metals can be cast successfully in bi-metallic metal form but in general it is preferable that the inner metal have a lower melting point than the outer metal (Table 11-1).

Bimetallic casting is difficult with alloys having different properties. For example, if the conductivities of cast iron and cast steel are not sufficiently close, cracking or spalling can occur. Therefore, either cast irons of different composition or such a combination as 18-8 stainless and a carbon steel are used. In the casting of the latter, the carbon content in the carbon steel is restricted to allow solution treatment of the 18-8 stainless steel.

When considering any combination of alloys where the inner metal has the highest melting point, the dimensions of the casting and the quality of bond required must be

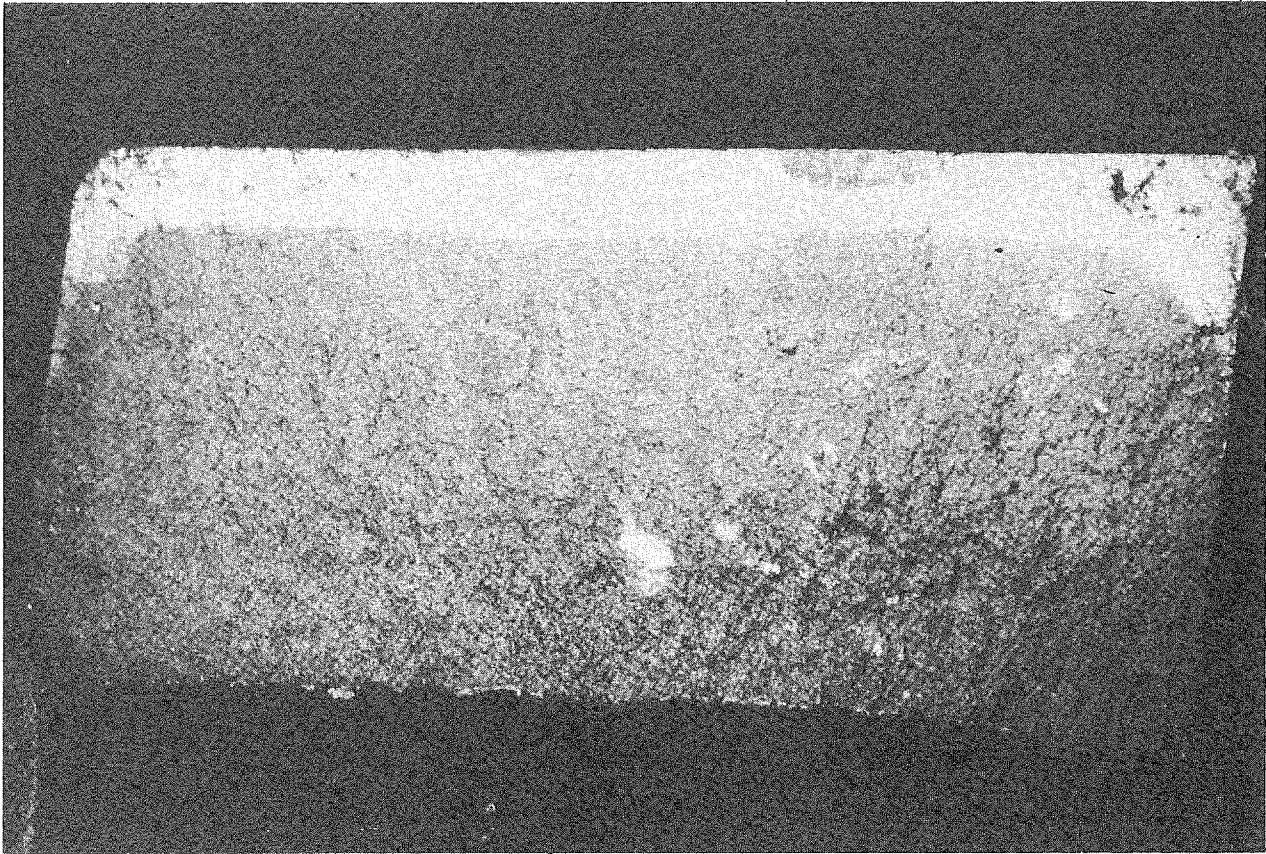


Fig. 11-1. Ni-hard is poured to form the hard outside diameter. The soft iron on the inside is cheaper and readily machinable. This grinding roll is about 30 in. in diameter by 20 in. high.

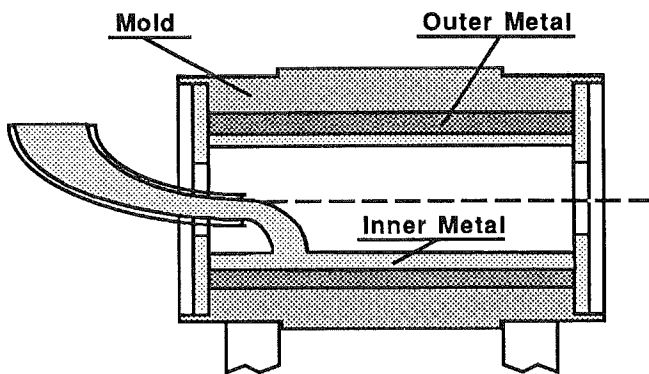


Fig. 11-2. Pouring a dual metal casting.

Table 11-1.
Successful Bi-Metallic Combinations

Outside Metal (Higher melting point)	Inside Metal (Lower melting point)
Steel	Copper
Steel	14% Si iron
Copper	Gray cast iron
Steel	Cupro nickel
Steel	Monel metal
Steel	Stellite or Hastelloy
Cast iron	Stellite or Hastelloy
Copper	Stellite or Hastelloy
Steel	Pure nickel
Mild steel	Martensitic white iron
Stainless steel	Gray iron
5% Chrome steel	Stainless steel
Low alloy steel	27% chrome cast iron
Ni-hard	Gray cast iron

taken into account. But when the melting point of the inner metal *appreciably* exceeds that of the outer metal, there is a marked tendency to form defective areas at the zone where the two metals join.

Bi-metallic castings for a wide range of applications have been successfully produced. For example, corrosion-resisting rolls for the textile or paper industries are made, in which an outer shell of a suitable stainless is backed by gray cast iron.

OXIDATION PRONE

Some metals are very subject to oxidation or even violently reactive with air and, therefore, cannot be melted or poured when exposed to the air. Such metals are melted and poured in a vacuum. Quite naturally, any metals that are melted and poured in a vacuum are much more expensive to process than those which can be handled in air.

Alternatively, a controlled atmosphere can be used for many metals. If the controlled atmosphere is maintained until the casting has solidified, there will be little or no oxidation with the result that the castings can be utilized right up to the inside diameter.

Copper-base alloys are highly oxidizable. If a centrifugal casting is made with any of the copper-base alloys and a wall section of 1 in. (25.4 mm) or more, there will usually be a highly oxidized surface on the inside. Sometimes as much as $\frac{1}{4}$ in. (6.35 mm) or more of machining is required to remove the oxidized interior surface. This can be quite expensive and wasteful.

To eliminate the oxidation of the metal, the centrifugal casting can be poured in a relatively "controlled atmosphere." It is necessary to connect the machine to a source of natural gas in such a way that the gases, after being ignited, flow into the runner pot, then through the mold

and out the rear end of the mold. This gas should completely displace the air so that the interior of the mold is then composed of the products of combustion of the gas. If the molten metal is poured into the runner pot which is enveloped in this flame, there will be very little oxidation caused during the time that the molten metal passes from the ladle into the runner pot, then into the mold.

Other inert gases can be used. Nitrogen is very satisfactory, as well as helium. However, both of these are expensive and are invisible. The products of combustion would be carbon dioxide and carbon monoxide, as well as the nitrogen, which would be in the air anyway. None of these would cause oxidation of the metal, and therefore may be considered satisfactory.

While this controlled atmosphere technique is very suitable for the copper-base alloys, it can also be used with some of the aluminum alloys, as well as some of the stainless steel alloys. The stainless steel alloys, which contain large amounts of chromium, are very subject to oxidation. Generally this is not a serious effect and does not warrant the use of controlled atmosphere. However, in many cases, the use of the very inexpensive controlled atmosphere technique is warranted.

ELECTRIC MOTOR ROTORS

Alternating current electric motor rotors are produced from steel stampings that have a carefully designed system of holes arranged in a circle about the center. A stack of these laminations are assembled slightly skewed. Originally, copper bars were assembled in these holes and connected together at each end by welding. This was a very expensive way to produce a squirrel-cage electric motor rotor.

These rotors are now produced by die casting, pressure casting, and centrifugal casting (centrifuging). Centrifugal

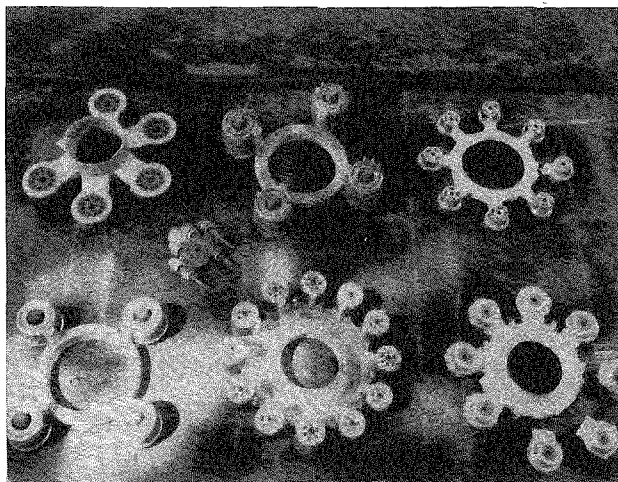


Fig. 11-3. Electric motor rotors, less than 2 in. in diameter, are poured in clusters using various types of gating. Normally, high-purity aluminum is used.

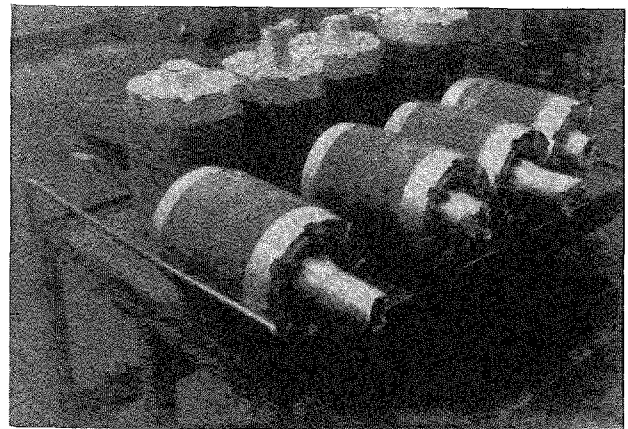


Fig. 11-4 Electric motor rotors, 8-24 in. in diameter, are poured singly and spun about their own center.

casting has proven itself to be the method for producing the highest quality as well as the most economical system.

Figure 11-3 illustrates several arrangements for producing rotors. The plan of gating and feeding the rotor casting represents a combination of foundry expertise and experience. The aluminum that is cast is usually pure aluminum, which is not the easiest form of the metal to cast. After a trial cast is made a few rotors are installed in motors and electrically tested. The centrifugally cast rotors have proven to have the highest efficiency. The most successful distribution in size for producing rotors centrifugally is from $\frac{1}{2}$ to $1\frac{1}{2}$ in. (12.7 to 38.1 mm) in diameter and 5 in. (127 mm) or larger. It is not always possible to design the gating system for the intermediate sizes properly to produce the perfect quality required.

The larger-sized rotors are produced singly, as illustrated by Figure 11-4. In this method the aluminum is poured down through the center in such a manner as to fill the

mold from the bottom up. The larger casting machines, which produce the large rotors, are preferably mounted in a pit.

BABBIT BEARINGS

There are many applications for bearings for which the well-known babbitt bearing is most suitable. These bearings are produced in sizes from 1 in. (25.4 mm) to 6 ft (1.829 m) in diameter! (Fig. 11-5.)

Machines are made to cover a wide range of dimensions (see Chapter 2: Types of Machines) and must be easy to adjust to the varying sizes and configurations of the bearing housings. Not all bearing housings are symmetrical. Several different babbitt alloys are cast, some of which require a controlled atmosphere as well as carefully controlled cooling.

These large bearings are used in rolling mills, electric motors, and alternators, as well as in large mining machines.

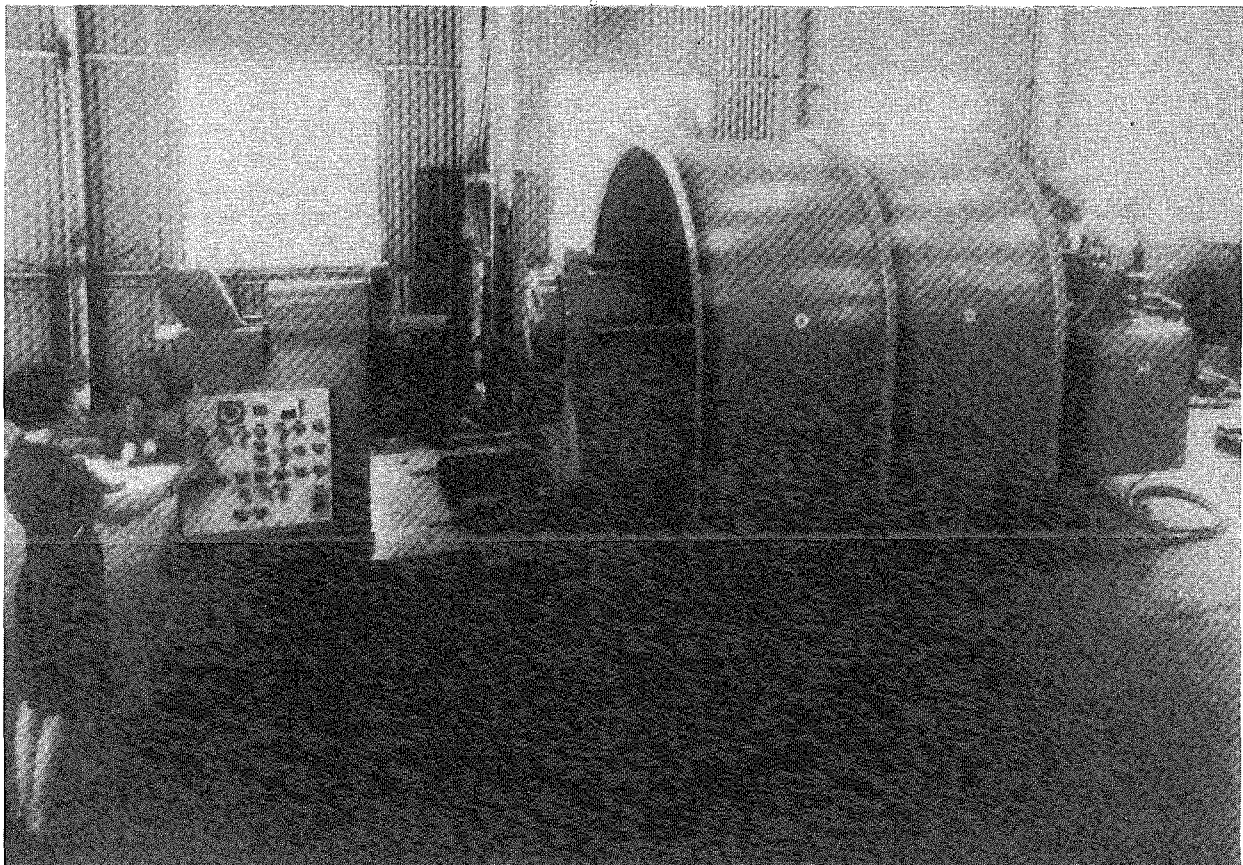


Fig. 11-5. This babbit lining machine can babbit-line bearings up to 6 ft in diameter and 6 ft in length. Such bearings are used as rolling mill bearings.

Safety

INTRODUCTION

With the advancement of research in centrifugal casting, machinery requirements have been analyzed and incorporated into the equipment, safety being the chief consideration.

A centrifugal casting machine should incorporate all the safety factors possible, based on a thorough knowledge of dynamics and statics (Fig. 12-1).

FORCES

Centrifugal force increases directly as the square of the RPM and directly as the length of the radius, sometimes growing to awesome proportions. Suppose the cover of a mold is held down with a number of $\frac{3}{4}$ -in. (19.05-mm) bolts spaced equally on a 20-in. (508-mm) bolt circle, and assume that the mold is rotating at 1500 RPM. Each of these bolts would weigh the equivalent of 639 lb, representing a terrific strain on the cover and mold. Likewise, if the mold were of 20-in. (508-mm) diameter, the bursting strain on the mold bore would be 5600 psi, while the metal was molten (the critical period in the casting cycle). Beware then of thin-walled molds or the metal will burst through with volcanic force.

Another force seldom considered is the velocity developed in the parts of a rotating mass. Returning to the cover bolts, if one of these were to break loose, the destructive force would be the equivalent of dropping a building brick on a man's head from a height of 16 ft (4.877 m).

Centrifugal molds must be centered and dynamically balanced as much as possible. This is true, not only from a casting process angle (to obtain concentric bores), but from the standpoint of safety. Assume that a 100-lb casting 20-in. (508-mm) long is poured into a mold that is $\frac{1}{8}$ in. (3.175 mm) off center. The unbalanced force at 1500 RPM would cause a bending moment of approximately 25,000 in.-lb, which is approaching the safe limits of a $3\frac{1}{2}$ -in. (88.9-mm) shaft without even considering dead load and shock load. Also, there is an additional 1600-lb load placed on the bearing. These conditions, of course, will vary considerably with the individual type of construction, but should give an average cross section as to what can be expected. In the main, shafts need be designed only for bending, as the torque is usually insignificant in comparison to the bending moment.

The attachment of end plates to close off the ends of cylindrical molds is of great importance. If this is not done securely, the force of the molten metal, while spinning, may dislodge the end plates, allowing the molten metal to be thrown from the mold and cause serious injury. It is, therefore, necessary to consider how to calculate the force developed by the molten metal against the end plates.

Calculating Force

Since centrifugal force is defined as an outward force exerted by a body in circular motion, one might wonder how this force can be exerted longitudinally with a cylindrical mold. If we were dealing with a solid body the centrifugal force would, in deed, be only in an outward, radial direction. The fact of the matter is that early in the casting process, we are dealing with liquid metal, each and every drop of which contributes to the total centrifugal force being developed. The total mass of the molten metal, in turn, is restrained by the mold itself by an equal and opposite force called "centripetal force." The net effect of these opposed forces is to put the molten metal in compression, creating a hydraulic pressure transmitted uniformly through the liquid metal. Thus, the hydraulic pressure of the molten metal is exerted against the end plates of the mold as well as against the cylindrical mold wall (Fig. 12-2).

To determine the loading against the end plates we must determine the pressure within the liquid metal during spinning. This value, multiplied by the area of contact between the metal and the end plate, will give the level of loading.

We can determine the pressure developed within the molten metal by starting with the equation

$$F = 0.0000142 \times d \times W \times N^2$$

where: F = Force per square inch
 P = Total force on the area
 N = RPM (revolutions per minute)
 W = Weight
 d = Diameter
 d₁ = Inner diameter
 d₂ = Outer diameter
 A = Area of contact

This equation gives total centrifugal force exerted against the mold by the entire body of molten metal cast (weight, W) whose diameter of rotation is d .

Consider not the entire body of molten metal but only a small, unit volume. For convenience, select one cubic inch (a cube measuring 1-in. per side). The weight, W , of this unit volume will be numerically equivalent to the density of the metal (since density is defined as weight per cubic inch). The next step is to select a diameter of rotation in accordance with the equation. The unit volume of metal we have chosen for our calculation is most conveniently assumed to be midway between the inner and outer diameters

of the spinning cylindrical casting. Thus, if the inner and outer diameters are d_1 and d_2 , respectively, the mid-diameter will be the average $\frac{1}{2} (d_1 + d_2)$. Inserting these values in the equation, we obtain

$$P = (0.0000142 (d_1 + d_2) W \times N^2) / 2$$

Note that in this modified equation, we have replaced F with a different term, P . This is merely to distinguish between the value of total centrifugal force obtained from the first equation and the unit force exerted by a unit volume of molten metal against a unit area. To complete our calculation of force against an end plate, we need an equation

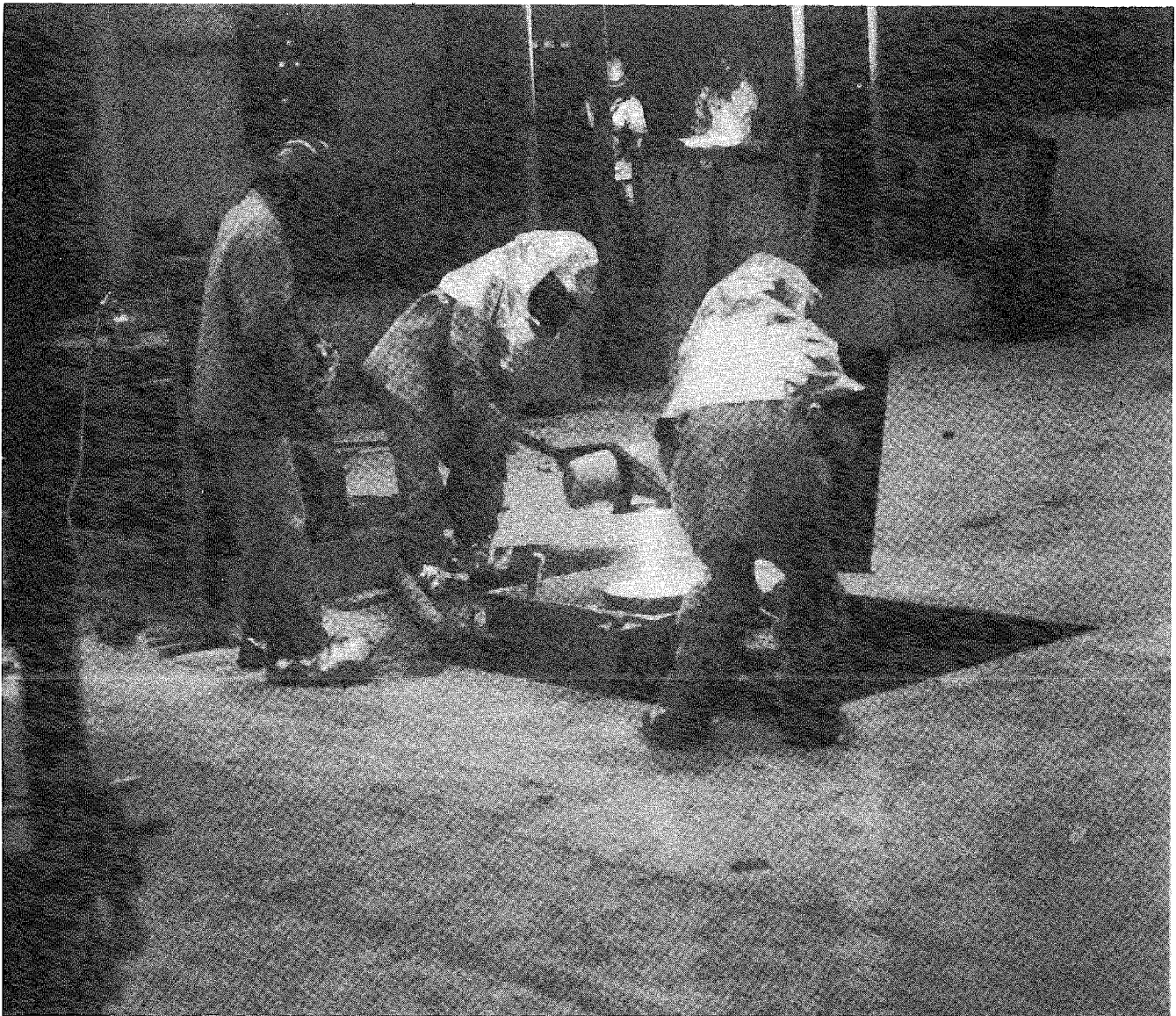


Fig. 12-1. Note the full safety protection incorporated by this pouring crew on a small vertical centrifugal casting machine.

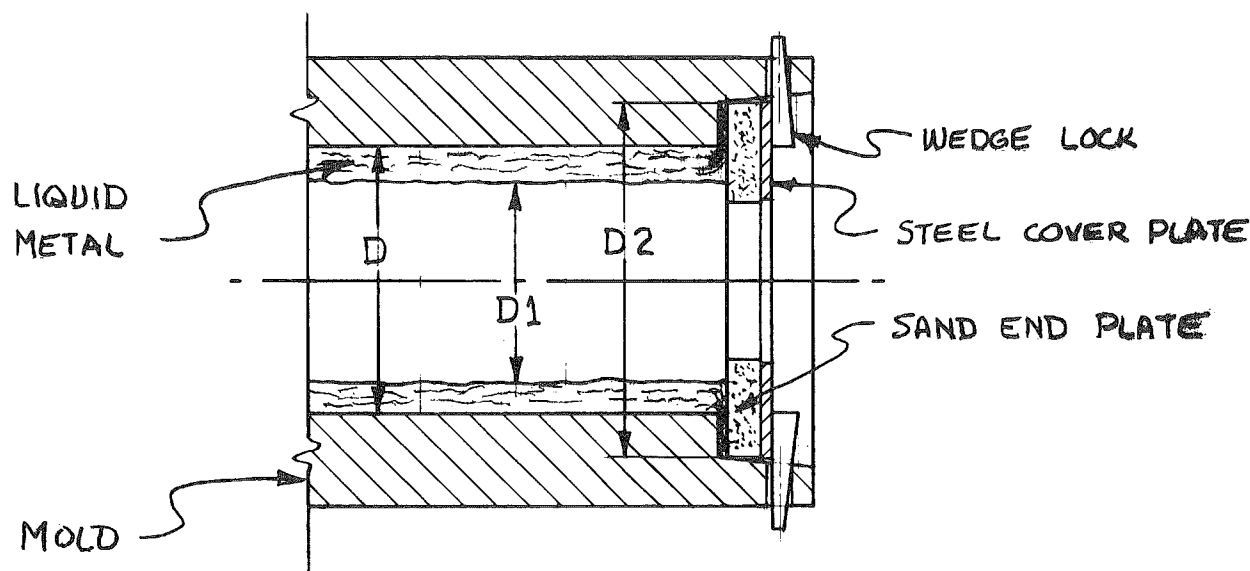


Fig. 12-2. Poor fit of an end core or inadequate wedge locks can result in a disastrous run-out.

expressing the area of contact between the plate and the spinning metal. This is given, in terms of the inner and outer diameters, by the expression

$$A = \pi/4 (d_2^2 - d_1^2) = .785 (d_2^2 - d_1^2)$$

Finally, the force against the end plate will be the unit metal pressure, P , times the area A

$$\text{Force} = 0.00000557 (d_1 + d_2) (d_2^2 - d_1^2) \times W \times N^2$$

Consider an example in which

$$\begin{aligned} d_1 &= 9 \text{ in.} \\ d_2 &= 16 \text{ in.} \\ W &= 0.276 \text{ lb/in.}^3 \text{ (cast iron)} \\ N &= 760 \text{ RPM} \end{aligned}$$

$$\begin{aligned} \text{Force} &= .00000557 (9 + 16) (256 - 81) (.276) (760)^2 \\ &= 3876 \text{ lb} \end{aligned}$$

HEAT WARPAGE

Warping of the various parts of a centrifugal casting machine is probably the largest source of danger. This condition, caused by the effect of the heat involved in casting metal, can distort a shaft during operation in such a manner that the entire load is shifted. Centrifugal force increases the bending moment and produces still more deflection. The action, therefore, is cumulative and rapid, and usually results in a broken shaft or a shattered bearing. To prevent this danger, shafts can be cooled by various means, such as air fins or water circulation. Warpage also causes danger in that molten metal creeps under covers and between parts, spraying the surrounding area.

Whenever possible, centrifugal molds should be self-centering. This can be accomplished by various methods, such as rotating rings or tapers. The advantage obviously lies in the fact that the casting will be symmetrical and there will be less mechanical stress, which will reduce the danger of flying parts.

FLYING METAL

One should never look into a vertically spinning mold during the pour, as it is possible for the metal to encounter moisture from a core or other foreign material and eject metal from the mold opening.

The same is true in horizontal casting. One should not immediately look into a horizontal mold during the pour. It is better to stand 5–10 ft (1.5–3 m) from the mold, opposite the end from which the pour is being made, and watch the progress of the metal as it moves down the length of the mold. It is still better to use a mirror to look into the mold, rather than stand in front of it. Any foreign matter in the mold, upon encountering the molten metal, could explode or turn to gas and blow molten metal out of the mold.

Guards

Normally, if a mold overflows from an excessive charge, the metal will run out one or both of the end plates and pinwheel into the air. This is not dangerous since a guard has been designed to catch all of this molten metal. When using the jump-the-gap method of pouring, one always expects a pinwheel at the completion of the pour. Therefore, an adequate guard should always be in place.

Various types of guards are available, such as those that raise themselves up and rotate so as to present an area of

the machine table to the workmen for mold removal and replacement. Another is a simple bail-type guard, which is removed by means of a crane or hoist.

In the case of very heavy machines it is better to use a concrete wall-type guard. The machine is merely placed between two heavy concrete walls with a steel cover that acts as the guard. The cover rides on tracks so that it can be moved longitudinally out of the way to replace molds, etc. At the pouring end of the machine, a car containing the runner pot is used. This incorporates a guard to protect the workmen from a runout during the pouring operation.

Horizontal machines should be enclosed to protect workmen during the pouring-spinning operation. It is possible for a runout to occur from one or both ends of a spinning mold which would cause a pinwheel of molten metal to be ejected from the end of the mold. These guards are made of steel, some with a hinged top so that molds can be readily removed and replaced. In other cases, the entire guard is lifted off the machine to replace the mold. For very small machines, it is usually possible to remove the mold from under the guard quite easily without removing the guard from its normal position.

Controls for starting and stopping the machines should be located in such a position that if anything goes wrong with the cast, the operator will not have to leave his operating station. He will feel protected and be away from any abnormal spill or breakage of the mold.

SAFETY IN CENTRIFUGING

Centrifuging presents similar safety problems to centrifugal casting but different in detail. It is sometimes possible to locate the casting so that part is centrifuged and part is a true centrifugal. In other cases, the entire casting lies on one side of the center of rotation. This is truly a centrifuged casting and depends upon centrifugal force to merely cast under pressure. For centrifuging, much less angular velocity is required, which is a distinct advantage. In some cases, the mold is counterbalanced to offset part of the unbalanced weight. More often, a number of castings are placed symmetrically about a common sprue. This not only balances the setup, but also increases production, provided the intricacies of molding do not slow down the operation.

Troubleshooting—Defects

INTRODUCTION

Centrifugal castings have many of the same defects as static castings, but are far less prone to them. Such defects are gas holes (pinholes), cracks (tears), laps, shrinkage cavities, and nonmetallic inclusions.

Laps, tears, and wrinkles are particular hazards, and banding and raining are peculiar to centrifugal casting (Fig. 13-1). There is, however, a pronounced absence of haphazard internal shrinkage and inclusions. Conditions will sometimes occur in semi-centrifugal and, especially, centrifuging that more closely resemble those of static casting, depending on individual technique.

The successful production of both ferrous and nonferrous centrifugal castings depends on the composition of the metal, dimensions of the casting, and techniques developed. Heavy-walled steel tubes are the most difficult, since they are subject to hot tears, irregular segregation, laps, and refractory breakdowns. In thin-walled steel or cast-iron tubes or pipe, laps and cracks are serious problems. The copper alloys are not usually subject to cracks and tears and can be produced with fewer defects. Inspection procedures are simplified by the fact that the defects that do occur can usually be readily observed on the surface.

TESTING

The inspection methods chosen vary with alloy type and application, and should be most stringent with castings for aerospace and nuclear manufacture. Here, it is standard practice to subject the components in plain carbon and martensitic high-chromium steels to ultrasonic, radiographic, and magnetic particle tests, while austenitic steels and nickel alloys are examined by etching, radiography, and surface penetrants of the dye or oil and chalk types.

QUALITY CONTROL

If one accepts that the best way to maintain a high standard is not merely to reject defective castings but to prevent them, much can be done by correlating inspection results with the conditions obtained during production. This preventative aspect of quality control is one to which the centrifugal casting process lends itself more readily than does static casting.

The main device at the foundryman's disposal is control of such factors as temperatures, pouring rates, and rotational speeds, along with the many metallurgical variables associated with melting practice. By keeping records of these conditions, a background of experience is built up as to the influence of each variable on the specific defects, thus aiding the selection of remedial actions when departure from normal standards is observed.

Variables Influencing Quality Control

Metal Composition and Physical Properties

- fluidity and density of metal
- chemical composition differences between start and completion of solidification
- temperature and the extent of the temperature differences between the start and completion of solidification, i.e., the solidification range

Casting Size

- diameter, wall thickness, and length
- relation of mass of metal to cooling surface

Mold Material

- heat capacity and conductivity of mold
- mechanical properties of mold, especially at high temperatures
- properties of mold coating

Casting Process

- spinning speed of mold
- pouring temperature of metal
- pouring rate
- mold temperature
- cooling conditions

Most of the major troubles encountered may be avoided by paying careful attention to the variables listed. However, the formation of solidification shrinkage cavities adjacent to the inner curved surface must be regarded as an almost unavoidable part of the centrifugal casting process, analogous to the provision of feeder heads in static casting processes. This is especially true of short steel castings. In this case the depth to which shrinkage cavities occur can be minimized by correct foundry practices.

DEFECTS PECULIAR TO CENTRIFUGAL CASTING

Segregation Banding

The phenomenon called banding occurs only in true centrifugal casting, generally where the mold wall is in excess of 2–3 in. (50.8–76.2 mm). It occurs rarely in thinner wall castings. Despite the general impression, banding occurs in both horizontal and vertical centrifugal casting.

Bands are annular zones of segregated, low-melting-point constituents, such as eutectic phases and oxide or sulfide inclusions. The bands are characterized by a hard demarcation line at the outside edge, which usually merges into the base metal of the casting.

Most alloys are susceptible to banding, but the wider the solidification range and the greater the solidification shrinkage, the more pronounced the effects may be. This condition has been found when some critical level of rotational speed is attained, and has also been associated with very low speeds that would produce sporadic surging of the molten metal. Both mechanisms may be involved. Usually minor adjustments to casting operation variables, such as rotational speed, pouring rate, and metal and mold temperatures, will reduce or eliminate banding.

Various theories have been presented to account for banding. One theory is that vibration is the principal cause. During solidification, a zone of lower-melting-point liquid exists immediately adjacent to the main crystal growth. Nucleation can occur and, if disturbed by vibration, the banding phenomenon takes place. The theory further states that growth takes place from these new nuclei in such a manner as to form a sandwich of liquid metal surrounded by solid metal, which is isolated from the liquid bath at the bore.

Another theory proposes that banding can be caused by variation in gravitational force between the top of the mold and the bottom, and that centrifugal separation of the metallic constituents occurs once per revolution during solidification. This theory does not bear close examination inasmuch as it assumes that solidification will occur in a matter of seconds, even in very thick sections. This, of course, does not occur, as solidification of thick sections takes place over a period of many minutes.

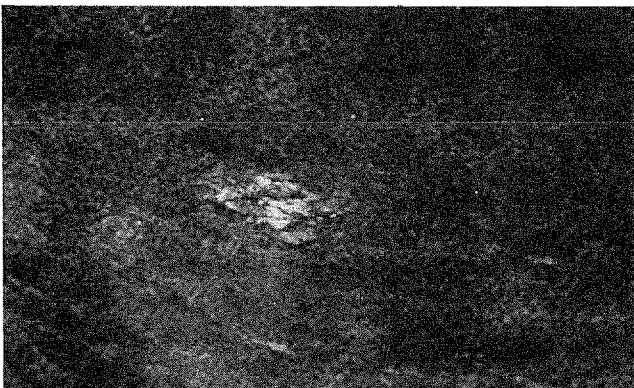


Fig. 13-1. Sand inclusion, probably caused by poorly mixed or applied mold coating or dirt in the mold.

Yet another explanation for banding affirms that the process is far less complicated; that there are irregularities in the flow of the liquid metal (incipient laps) as it enters the rotating mold. As the metal enters the mold, it forms a tubular casting that tends to solidify in the normal manner. However, if the additional liquid metal arrives at the particular position too late, the initial liquid metal has already or partially solidified, which would then cause a distinct lap, cold shut, or lamination; the discontinuity known as banding.

Close examination of the metal as it enters a rotating mold discloses that the metal generally does not flow continuously, but tends to surge longitudinally. There usually is a buildup of molten metal at the pouring end of the mold, with the result that the initial formation of the "first casting," so to speak, is covered a short time later by additional metal, but too late. It has been observed that, if using the same equipment, the same mold, and the same machine, but the pouring rate and pouring conditions are changed, the identical casting can be produced without banding. With other conditions, banding does occur.

Raining

In a horizontal machine, if the mold is rotated at too low a speed or the metal poured into the mold too fast, raining occurs; that is, the molten metal actually rains or falls from the top of the mold to the bottom. This phenomenon can be seen by looking into the *opposite* end of the rotating mold from which the molten metal is poured.

Raining occurs because the molten metal has not been accelerated to the speed of rotation of the mold. If the friction of the molten metal against the mold wall is low, due to too slow a spinning speed, the molten metal will not reach a high enough rotative velocity to overcome the force of gravity and will fall off from the top of the mold (Fig. 9-1).

One cause could be improper temperature. If the molten metal is at too high a temperature when entering the mold, its fluidity will be high and its viscosity will be low. It will be difficult for the molten metal to accelerate quickly enough to the rotative velocity necessary to overcome the force of gravity. This can be remedied by a higher spinning speed or, more easily, by reducing the pouring rate, particularly the pouring rate of the last half of the metal poured into the mold.

Another cause of raining may be due to a mold coating that is too smooth. In this case, a rougher mold coating can be applied. This will permit the metal to obtain a better foothold and gain velocity in order to catch up with the speed of the mold. A higher spinning speed can also be reached by increasing the speed of rotation; this increases the friction effect.

Vibration

Vibration will cause a laminated casting. It must be held to an absolute minimum by proper mounting, careful balancing of the molds, and frequent inspections of rollers, bearings, and other vital parts.

Machine vibration, the establishment of resonant frequencies, and improper dynamic balance are conditions that produce two types of poor quality castings. One type demonstrates a larger as-cast central bore at the muzzle (non-pouring end) than at the breech (pouring end) of the casting. This difference in hole size is accompanied by segregated dark spots in the center of the tube, which contain segregations of carbon, sulfur, phosphorus, and nonmetallic inclusions. Severe machine vibrations also produce castings subject to circumferential carbon, phosphorus, and sulfur segregation rings during solidification; rings that become more frequent and pronounced as the vibration increases.

CAUSES OF DEFECTS

Improper Pouring Techniques

Many defects, either metallurgical or mechanical, such as laps and cold shuts, can be directly attributed to the method of introduction of the molten metal into the mold and surging of the molten metal during its progress down the longitudinal path to the far end of the casting cavity. (See also "Hot Tears" and "Segregation" later in this chapter.)

Every effort should be made to see that the flow of metal is smooth and continuous, and that the metal has initial velocity in the direction of rotation. When these efforts are exerted to produce a uniform, smooth operation, banding and other defects seldom occur.

Shrinkage Cavities

When molten metal is introduced into the mold rapidly, the degree of superheat is important—as is usual with cen-

trifugal casting. Excessive metal temperature slows solidification from the outside diameter more than it delays solidification from the bore (due to the heat buildup in the mold mass) and gives the worst conditions for the formation of deep shrinkage cavities.

The temperature of the molten metal entering the mold and the rate at which the liquid bath builds up are important in determining whether or not solidification will occur to an appreciable depth from the bore. If the molten metal is poured slowly, so that the liquid bath is only just kept in advance of the crystal growth from the mold wall, directional solidification will be maintained across the full section and the chances of obtaining shrinkage cavities near the bore will be at a minimum.

Cold Shuts (Laps)

Cold shuts are caused by improper pouring techniques; irregular coverage of the mold surface produced by cold metal, turbulent pouring, interrupted or excessively slow pouring. Founders usually try to use the fastest possible rate of pouring temperature possible before tearing occurs. Besides technique, the inherent fluidity of the molten metal, especially those metals carrying strong oxide surface films, also is an influential factor, particularly in the case of highly alloyed ferrous metals.

Layer formation causing cold shuts and the lack of fusion at these layers is shown in Figure 13-2.

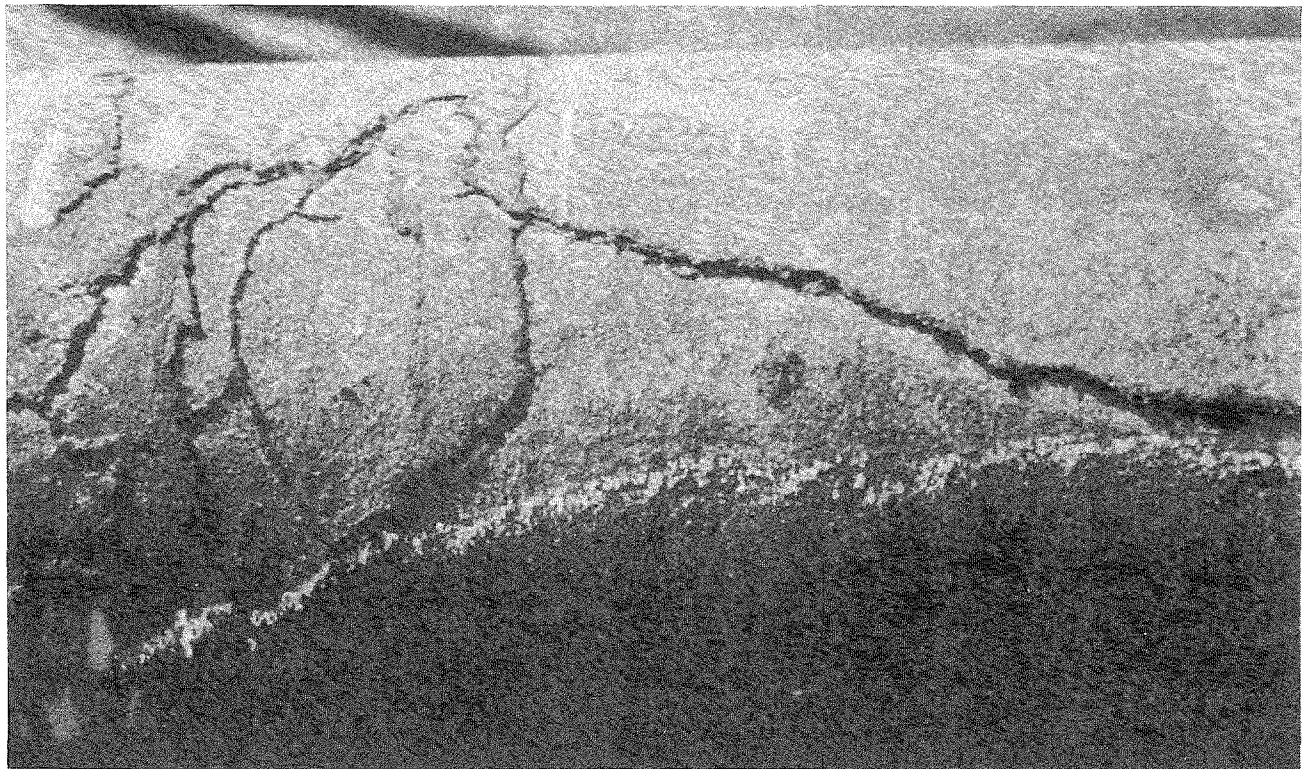


Fig. 13-2. Example of cold shuts.

Improper Rotational Speed

Too Slow

The pouring rate should be sufficient to keep the metal advancing over the mold surface continuously until the end of the mold is reached. If it stops, even momentarily, cold shuts result. If a continuous flow of metal is arranged during the pouring operation and if there is no surging, the speed of rotation is adequate to prevent raining. A smooth flow of molten metal into the mold helps prevent segregation banding. (A more detailed discussion of segregation can be found later in this chapter.)

Too Fast

The mold wall surface, under all conditions, will be traveling with a rather high velocity, usually from 1000 to 2000 ft (304.8 to 609.6 m) per minute. The metal striking directly on the surface produces a marked cutting or erosive action and if the mold surface becomes broken, casting defects will result.

Another type of defect is caused by a vibrating or rough mold splashing the inflowing stream of molten metal and throwing globules of molten metal on the uncovered mold surface. The tendency toward both of these defects is lessened as the spinning speed is reduced.

Excessive speed produces circumferential tensions high enough to cause excessive vibration. This, in turn, causes segregation banding, radial cracks, and longitudinal tears in the solidifying metal as it shrinks away from the mold wall, and unwanted segregation of alloying materials.

A different type of defect associated with high spinning speed is the formation of cracks on the casting surface contacting the mold. In cast iron these cracks occur in the quick solidification, high shrinkage analysis iron, and under mold conditions that cause rapid cooling. Exact cause of these cracks cannot be shown clearly, but the standard remedy for them is to reduce the spinning speed about 5%.

Improper Temperature

Too low a casting temperature, along with slow pouring, gives rise to cold lapping and possible gas entrapment.

Segregation

Centrifugal castings are subject to various forms of segregation especially in heavy sections. Centrifugal separation of suspended crystals or insoluble phases can occur within the liquid in either direction, creating a tendency for the less dense constituents to be transported towards the center. At a more advanced stage of solidification, low-melting-point liquid can flow outwards through passages between the rigid network of interlocking grains.

Thus, the particular pattern of segregation in a centrifugal casting depends primarily on the mode of solidification. Assuming for example that differential solidification was to produce rejection of a heavier solute element, this would, under perfect directional solidification, segregate to the bore notwithstanding its greater density. Dispersed crystallization, on the other hand, provides opportunity for relative gravitational movement of solid and liquid in the same alloy;

therefore, the less dense crystals would be centrifuged towards the bore with the opposite effect to that previously encountered.

Examples of segregation include tendencies for phosphide eutectic to gravitate outwards in cast iron, for copper enrichment to occur towards the center in aluminum-copper alloys, and for lead to segregate to the outside of leaded gun-metal castings.

One of the unique advantages of centrifugal casting is the cleansing action of the molten metal, which takes place in the spinning mold. This applies to both solids and gases, and in either case, the metal in the mold must remain molten long enough for this action to take place. The problem is, if the mold is too cold, chilling will be so rapid that dirt and gas will be trapped in the peripheral portion of the casting before it gets a chance to work through to the bore. The solution is to have the mold hot enough to begin with and pour just as fast as possible.

The segregated inside of these tubes contains approximately 1½ times more carbon and a considerable higher phosphorus and sulfur content than the remainder of the tube, as well as a large amount of nonmetallic material. If this segregation becomes marked outside this inner wall, however, the quality of the tube will be reduced. This marked segregation is the result of either improper machine operation, large machine vibrations, or too high a pouring temperature.

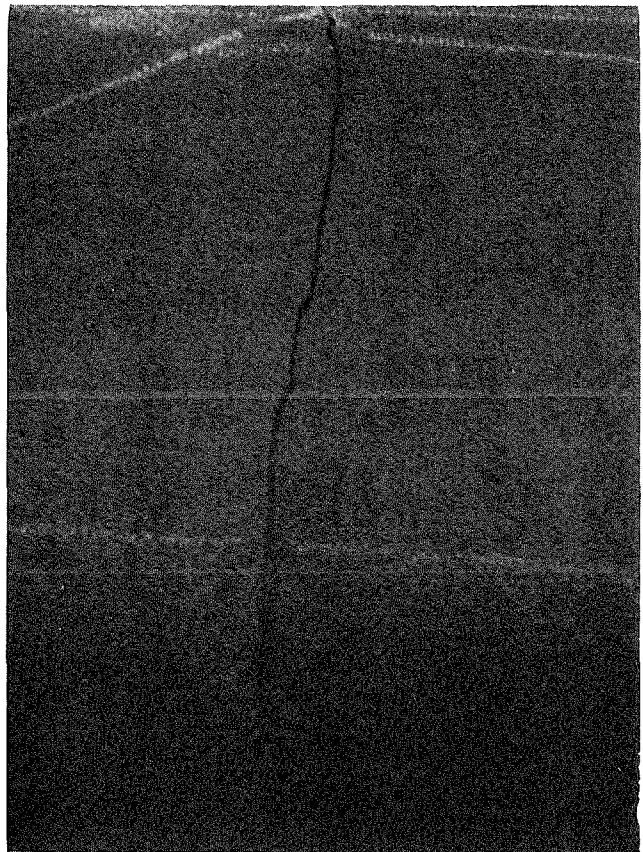


Fig. 13-3. Circumferential crack.

Breakage

When centrifugally producing cast iron pipes, such as soil pipe, in a permanent mold, the mold is coated before each and every cast with a refractory insulating coating. In some cases, it may be found that in an attempt to pull the pipe out of the mold, by inserting a puller on the bell end, it will pull the bell off the pipe, leaving a length of pipe in the mold. At times, the break, which almost invariably occurs at the junction of the bell and the body of the pipe, will occur even if the puller is inserted inside of the main body of the pipe.

The reason for this is the fact that too much coating is located at the curved portion of the pipe, where the main body of the pipe blends into the bell of the pipe. This junction is usually a rather heavy section and the metal at this point (while it is hot) is less strong than elsewhere. The result is that a crack can occur and cause the bell to break off.

This breakage problem can be lessened to a considerable extent by placing less coating on that particular junction point, or by reaching into the spinning mold after removing the spray lance and, while the mold is slowing down or even stopped, removing a small amount of the coating from that particular point. The cooling rate will be increased in that area and cause the temperature of the iron to lower, which will, therefore, increase the strength of the iron at that point.

Improper Molding Materials

Circumferential Cracks

Nothing peculiar to centrifugal casting causes this type of defect, for the same defect occurs in static practices, and the same precautions should be taken as in static casting. Circumferential cracks (Fig. 13-3) can occur unless particular care is taken with the composition of the molding sand. In pipe-casting the flanges at each end of the casting prevent longitudinal contraction of the casting after solidification. To prevent this, the molding sand should have relatively low hot strength to permit the casting to contract as it solidifies. Castings made with a flange at one end are usually not troubled with circumferential cracks, as the casting is restricted from longitudinal movement at only one end.

When using permanent molds to produce long tubes, it is very important that the end plates fit the mold perfectly. If they do not fit, a flange or fin can be produced at each end of the casting. This will prevent longitudinal contraction with the resultant circumferential crack.

Pinholes (Gas Holes, Blowholes)

Few pinholes occur in centrifugally cast pipes, since they solidify under the influence of centrifugal force. However, when liquid metal contains a large amount of gas, or the moisture content in the mold and the coating is not properly controlled, pinholes and blowholes will occur. These defects occur in metal molds because the metal casing does not have porosity for the gas to escape and the solidification rate of the metal is high (Figs. 13-4, 13-5).

Pinholes are likely to occur on thinner pipe. Slag holes and cold shuts are primarily housekeeping defects. Good

skimming and ladle and trough cleanliness will control this defect.

Pinhole defects can be avoided by

- using steel instead of cast iron molds
- making the mold carefully and maintaining its temperature accurately
- not using coating materials that contain free water of crystallization
- maintaining an accurate molten metal temperature and not using an excessively high casting temperature

Holes can be caused by an excessively high pouring temperature. Corrective measures include elimination of gasing possibilities; use of an exothermic pipe eliminator to promote unidirectional solidification and the lowest pouring temperature possible without causing cold shuts.



Fig. 13-4. Pinhole defect on section of a bronze casting.

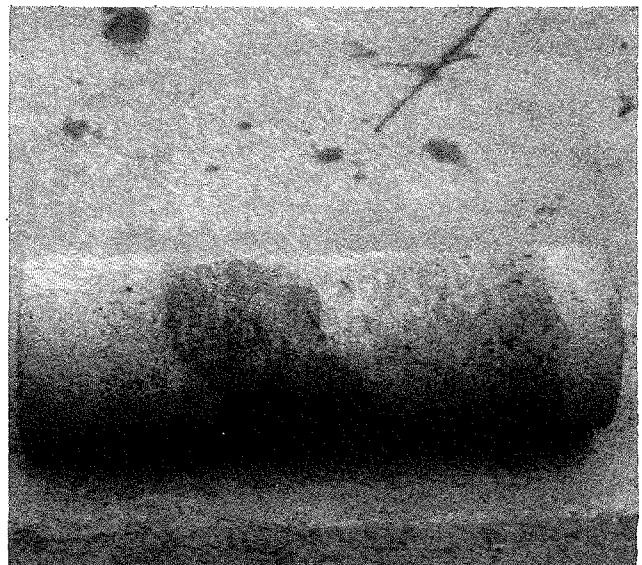


Fig. 13-5. Pinhole defect in an aluminum casting where the mold coating was not sufficiently dried.

Pinholes can be present as the conventional rounded blowhole or take the form of elongated radial pinholes following the direction of solidification. Even when gas is trapped, the high pressure of the metal compresses the gas to a much smaller volume than it would have ordinarily. As it is usually trapped on the surface, the smaller gas pocket requires less allowance for the stock necessary for its removal.

One common cause of pinholes is moisture retained in the mold coating or some constituent of the coating that turns to a gas when the molten metal comes into contact with it. This gas tends to migrate and the easiest path, in most cases, is through the molten metal. However, when the molten metal is in the process of solidifying, pinholes of gas will become fixed, especially as they emerge from the coating.

Usually a type of bentonite is used as the gelling agent in mold coating. If the bentonite is not thoroughly mixed with the water (the usual vehicle), it can cause the pinhole defect. Water of crystallization exists in the dry bentonite. The heat of the molten metal can cause this water of crystallization to vaporize, causing the pinhole defect. If the mold coating has permeability, the gas that is formed can travel longitudinally between the molten metal and the mold wall and, thus, escape to the atmosphere. This, then, eliminates the possibility of the pinhole defect.

In bronze castings and ferrous castings the pinholes appear as bright shiny spots on the outside of the casting and pockmarks on the inside. The diameter of the hole is very small.

Very thin castings will generally not be subject to the pinhole defect because the metal solidifies too quickly for the gas to penetrate. In the case of very thick-walled castings, the rate of solidification is so very slow that the gas produced generally passes through the molten metal before it solidifies. Thus, we see that, usually, only castings having a wall section of from approximately $\frac{1}{4}$ to 1 in. (6.35 to 25.4 mm) are subject to pinholes.

They also arise from gas dissolved in the metal. The dissolved gases are hydrogen, oxygen, and nitrogen, and can usually be minimized by careful selection of raw materials, drying, a controlled carbon boil where applicable, and degasification. Pinholes also result from carbon monoxide from over-heated ferrous (pearlitic) molds that have developed an appreciable oxide skin. This particular phenomenon is sometimes observed during the centrifugal casting of gray iron and copper alloys in cast-iron molds, and can give rise to puzzling internal cavities.

With most alloys, gas from all sources tends to be additive in its cavity-forming effect. Borderline cases of slightly gassy metal, which would not normally cause trouble, can cause cavities when cast in slightly damp molds. Several theories have been proposed to explain how steam, evolved at a mold surface, can cause pinhole porosity in steel castings. The basic suggestion is that a bubble of either hydrogen or carbon monoxide is formed in the molten metal by interaction between the steam and the metal. The bubble then rapidly grows as the dissolved gases diffuse into it. What-

ever the actual mechanism involved, the fact that ferrous alloys containing titanium or aluminum are amongst the materials least prone to gas trouble suggests that oxygen plays a prominent part. When alloys containing high concentrations of dissolved gas are cast in perfectly dry molds, the tendency is for the gas to accumulate in the liquid metal. They will then solidify and form large cavities in the feed metal region where shrinkage porosity normally occurs. Both this effect and surface pinholing from mold gases can be reduced to some extent by considerable increases in spinning speed.

Cold Shots

Cold shots are small globules of metal embedded in—but not entirely fused with—the casting. These are not to be confused with *cold shuts*, which are a form of misrun, appearing as a crack or seam.

Some chief causes of cold shots are high moisture or excessive gas released from molding sand; clay balls in the sand; undercured cores or excessive gas from core, core wash or core paste; poorly dried molds; excessive slicking of mold; metal of a composition prone to rapid oxidation (prevents shot from re-dissolving); too much phosphorus in metal (centrifugal casting). The particular defect shown in Figure 13-6 was cured by ladle additions of silicon.

MISCELLANEOUS DEFECTS

Segregation

Segregation can be caused by several variables; the following ones can lead to single or multiple segregation bands:

- uncontrolled vibration resulting from excessive high rotational velocities in out-of-balance systems
- rotation at low speeds, where raining of the molten metal occurs
- fast pouring rates which lead to splashing
- excessively high pouring temperatures
- slow solidification rate—occurring more frequently in thick-walled castings produced in sand lined molds

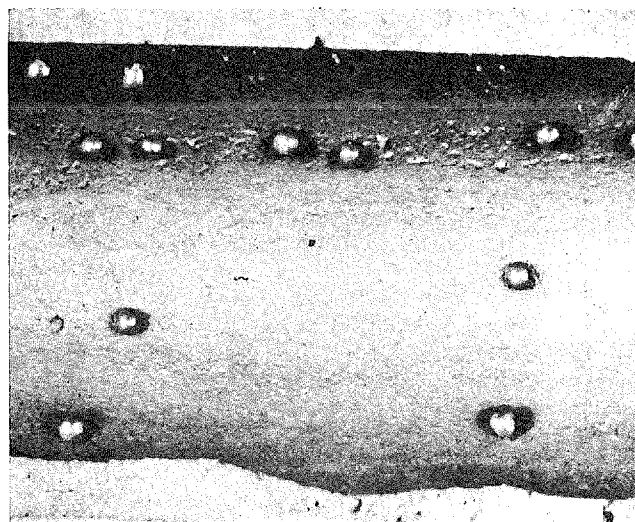


Fig. 13-6. Cold shuts that showed up on the inside surface of centrifugally cast iron pipe.

Inside Surface Shrinkage and Cracks

To ensure a completely sound and uniform density of metal, solidification must be progressive from the outer to the inside surface. In this manner solidification contraction of each layer is compensated for by the still-liquid inner layers, and shrinkage is avoided. If, however, the metal is poured rapidly and considerable cooling occurs at the inner surface (as is sometimes the case in thick, short tubes and liners produced in small horizontal machines), shrinkage in the casting does result. This inner porosity is produced because solidification occurs from both the inner and outer surfaces simultaneously, and the last metal to feed inside the casting exhibits this shrinkage.

This type of defect is prevented by either pouring so slowly during rotation that solidification is unidirectional, or placing an exothermic or insulating material on the inside surface of the metal immediately after pouring has been completed.

In casting with metal molds, directional solidification occurs from the outside surface. Therefore, the molten metal on the inside surface acts as a feeder head and there are no problems with shrinkage cavities.

With sand molds, however, the cooling rate from the outside surface is low and cooling occurs from the inside as well as the outside surface. Shrinkage cavities can occur where the solidification fronts from the inside and the outside surfaces meet.

To avoid this, the temperature at the inside surface should be kept high enough so that controlled directional solidification is obtained. Heat insulating material or slag can be poured into the pipe for this purpose, but it presents many operational problems. It is difficult to eliminate the problem of inside surface cracks completely. In general, this problem is alleviated by allowing generous machining tolerances on the inside surface.

Misrun and Liquid Interfaces

These defects rarely occur in thick pipes but are liable to occur in thin ones, particularly when cast in metal molds. The causes are:

- casting temperature too low
- pouring rate too low
- speed of rotation during casting too high

The liquid metal moves in a spiral fashion in the mold. If the speed of rotation is too high, it takes a long time for the liquid metal to reach the other end. It is possible, therefore, for the liquid metal in a thin pipe to lose enough heat and solidify before it reaches the other end, causing a misrun.

Sand and Slag Inclusions

If a sand-lined mold is dried unevenly or tamping of it is not uniform, molten metal can erode part of the sand during pouring and penetrate into the sand of the mold, causing sand inclusions.

Slag can become trapped in the metal and cause slag inclusions. In the case of top pouring, the slag is poured from the ladle with the molten metal. In the case of bottom pouring, slag can form while the hot metal passes through the nozzle.

Penetration and Dips

The penetration of sand in a sand-lined mold is caused by the high pressure exerted by the centrifugal force of the molten metal. If the metal temperature is too high, sand penetration occurs. This can be particularly severe when the sand grains are coarse.

A dip is a depression in the uniform thickness of the casting being centrifugally poured. The degree of dip varies, depending on the thickness of the applied refractory coating. In general, a dip occurs easily when the coating is too thick.

The properties of the bentonite used in the refractory coating also have a large effect. If dips continue to occur, the amount of bentonite should be decreased. One should also be careful about the fact that large differences exist between different shipments of silica flour.

Heavy refractories, such as zircon reduce this penetration. It is interesting to note, however, that longitudinal and transverse cracking accompany the use of this material. The lower thermal expansion associated with the use of zircon is probably responsible for this effect.

Longitudinal Cracks (Hot Tears)

In true centrifugal castings, longitudinal cracks (hot tears) are encountered primarily during the early stages of solidification in which the highest rotational speeds are employed. The hot tears occur when contraction of the casting, combined with expansion of the mold, generates circumferential tensile hoop stresses. These stresses exceed the cohesive strength of the metal at temperatures in the solidus region and rupture the thin outer shell. During the early stages of the casting operation, the initially solidified skin ceases to be supported by the mold surface and has to resist the internal pressure of the molten metal. An air gap appears through the combined effects of solidification contraction in the casting and thermal expansion in the mold. If the outer shell is too weak to withstand the stresses imposed upon it, a hot tear will be formed, usually in the longitudinal direction.

The stress required to produce tearing depends on the alloy. Since hoop stress is proportional to the square of the RPM and of the radius of rotation, excessive speed is the factor most directly concerned as a production variable. Pouring temperature, pouring speed, and mold temperature are also involved; they determine the temperature distribution and development of cohesion in the casting in relation to the rate of buildup of hydraulic pressure and hoop stresses in the solid shell.

Consideration of the stages through which the properties of an alloy pass on cooling from the liquid suggests that tearing can best be avoided by rapid cooling of the outer

region of the casting, below the brittle temperature range, just above the solidus. The metal in this region can then sustain stresses, while the remainder of the section passes through the critical stage. The best conditions are obtained from a combination of a moderate pouring temperature and slow pouring; the latter serves the dual purpose of maximizing the temperature gradient and delaying the development of hydraulic pressure, relative to the growing strength of the outer shell. Tears are more prone to occur, by contrast, under shallow thermal gradients, which produce the brittle condition across much of the radial section at one time.

When casting into metal molds the other major factor in tearing is the rate of mold expansion. This can be reduced, and loss of support for the casting delayed, by increasing the thickness and thermal capacity of the mold and by preheating to reduce its further expansion on casting. Mold temperatures of 500–700F/260–371C are employed for this purpose.

Circumferential tears in tubular castings and tears in semi-centrifugal and spin castings can result from contraction hindrance by the mold. This is a similar problem to that encountered in static casting. Tears in the longitudinal direction are seldom found in sand mold castings.

Stuck Castings

Castings stick in the mold due to the mold becoming too hot, whereby the casting and the mold expand and contract

together. To correct this problem, the cooling water (See Chapter 7: Mold Heating and Cooling) should be used for a longer period of time.

An improper or improperly applied coating can also cause sticking. Here, it will help to clean the mold thoroughly, correct and re-apply the coating. Too thin a coating will also cause castings to be difficult to remove.

A metal mold develops checks or cracks on its inside diameter, which makes the castings progressively more difficult to remove. This surface should be smoothed from time to time with a grinding wheel.

Operational Cracks

Cracks occur due to mistakes in operation and because of casting stresses. Cast iron pipe in a sand mold is ejected by hydraulic pressure. Uneven loading in this operation can crack the pipe at its ends. To avoid this, it is necessary to push the entire area of the pipe end. Cracking can also be avoided if the carbon content is restricted, the casting temperature lowered, or the mold slowly cooled by closing both ends after casting.

Careful stirring of the melt to assure a homogeneous mixture and the use of a thicker, uniformly applied mold coating, or higher mold temperature to promote a slower cooling rate, will eliminate this condition.

QUICK-REFERENCE DEFECTS GUIDE (Refer to text for detailed descriptions.)

Breakage: too much coating at body-bell junction (in cast iron pipe).

Broken surface: rotational speed too fast, temperature too high.

Cavities: spinning speed too slow (in gassy metal) (in feed metal region).

Cold shots: moisture, gas released from molding sand, clay balls in sand, undercured core, too much phosphorus in metal.

Cold shuts: pouring rate too slow, rotational speed too slow, ladle and trough dirty, metal surging, metal temperature too low.

Cracks: rotation speed too high, molding sand hot strength too high.

Dips: refractory too thick and/or uneven.

Gas entrapment: temperature too low, pouring too slow.

Globules: rotational speed too fast, mold too rough or vibrating.

Hot tears: rotational speed too fast (in conjunction with pouring temperature and mold temperature).

Longitudinal tears: high rotation speed causes excessive vibration which causes metal shrinkage away from mold wall.

Misrun: pouring speed too low, rotational speed too high, temperature too low.

Nonmetallic inclusions: vibration and improper balance.

Pinholes: temperature too high, bentonite not thoroughly mixed, spinning speed too low (with gassy metals), steel molds, moisture.

Raining: rotational speed too slow, metal pouring too fast, mold coating too smooth.

Sand inclusions: mold not dry enough, uneven tamping.

Sand penetration: metal temperature too high.

Segregation (banding): irregular rotational speed, excessive vibration, metal solidifying too slowly, metal temperature too high, low rotational speed causing metal surging.

Shrinkage cavities: improper pouring rate, metal cooling too fast at inner surface, metal too hot.

Slag holes: ladle or trough not clean enough.

Stuck casting: mold too hot.

Vibration (lamination, uneven bore): improper machine mounting, imbalance, faulty bearings/rollers.

Metallurgical Aspects

INTRODUCTION

The centrifugal casting process is not limited by the type or analysis of the particular metal being cast. It is true, of course, that different precautions have to be taken when casting from one metal to another. Experience has shown that not only all types of cast iron, steel, stainless steel, bronze, aluminum, and magnesium, as well as plastics, can be cast, but the process can also be used to pour sludge, which is a recovery method used in some metal processing systems.*

METALS IN GENERAL

If a material can be poured into a spinning mold, then some variation of the centrifugal casting process can be utilized to produce a "casting" from that material.

Even gold and silver are being centrifugally cast in the form of hollow ingots. The ingots are then further processed by forging, rolling, and/or stamping to produce parts for the jewelry trade. Gold is cast in the form of a hollow ingot which is then drawn and machined to eventually be a wedding ring! Gold cylinders are cast, split, flattened into a bar, and then rolled to produce gold foil.

There are, of course, many differences between the various metals being cast. The principal difference would be the viscosity of the material when it is at the proper temperature for pouring into a spinning mold. Some metals are highly reactive with oxygen. In those cases, the metal must be protected from the oxygen in the air by being melted and poured in a vacuum. In other cases, the molten metal may be protected by a controlled atmosphere such as CO₂ or nitrogen. The lack of fluidity in some metals or materials limits the size and dimensions of the castings to be produced. For example, it was found that it was very difficult to pour long lengths of gold bar. It was only practical to cast

gold tubes approximately $\frac{7}{8}$ in. (22 mm) outside diameter by $\frac{3}{8}$ in. (9.5 mm) inside diameter in lengths of 8 in. (203 mm).

When metals are cast it is usual practice to have most of the heat loss from the molten material go into the mold itself. In many cases the molds are water-cooled to prevent them from reaching an excessively high temperature. However, for the thermo-setting plastics the reverse is true. In this case, it is necessary to apply heat to the outside of the mold, which causes the thermo-setting plastic to set up and harden during the spinning operation. This technique is used to produce many different types of plastics, including plastic pipe.

One would naturally believe that the casting of high-lead alloys would cause some difficulty in centrifugal casting because of the tendency of the lead to separate from the copper (the main constituent of the mixture). However, this is not difficult at all if the mixture of a high-lead bronze containing as much as 20–30% lead is thoroughly mixed in the molten state and then poured into the spinning mold at a somewhat lower rotational speed than normal. Also, with the mold at a lower than normal temperature, and with adequate water cooling, there will be virtually no separation of the lead from the other constituents.

It is suggested that a small quantity of pure sulfur be added to the ladle and stirred into the metal immediately before pouring. The sulfur will "fix" the lead distribution throughout the copper and reduce any tendency toward lead separation. It is also suggested that immediately upon removing the casting from the mold it should be plunged into water (quenched). This will prevent the lead from oozing out of the "pores" of the body of the casting. The casting will then have essentially uniformly distributed lead throughout the body of the casting.

In general, bronze castings, when centrifugally cast in permanent molds, possess appreciably increased mechanical properties (Table 14-1). Laboratory tests have shown that when Navy M bronze is cast centrifugally, as compared with the same casting being made in sand, the centrifugally cast part has much finer grain size, a tensile strength approximately 17% above that of the sand casting, and an increase of over 50% in elongation.

*For example, in the case of scrap magnesium, the sludge is essentially a mixture of pure magnesium, oxidized magnesium, and chemical molten salts. It has become a practice to process the sludge by centrifugal casting. This results in the recovery of the pure magnesium, which is separated from the sludge or dross. Also, the very valuable salts that are separated from the sludge can be re-used.

Table 14-1.
Chemical Composition and Mechanical Properties of
Special Promet Bronze Bearing Alloys
(Mechanical properties are typical. Top figure is SAND, bottom figure is CENTRIFUGAL.)

Promet Alloy	Copper	Tin	Lead	Zinc	Nickel	Iron	Alum.	Mang.	Yield (a) Strength	Ultimate Tensile	Elongation	Typical B.H.N.
High Leaded Tin Bronze:												
2S	70.0	4.0	19.0		0.25				15,000	27,000	16	50
	75.0	5.5	23.0		1.00				17,000	30,000	10	55
6	76.0	4.5	12.5		1.00				17,000	31,000	16	55
	80.0	6.5	15.5		1.75				19,500	35,000	16	60
6SK	75.0	6.5	12.5		1.25				19,000	36,000	18	60
	79.0	8.0	15.5		1.75				21,500	40,000	16	65
782	65.0	7.0	20.0		0.25				15,000	24,000	19	55
	72.0	9.0	24.0		1.00				19,000	31,000	17	60
712	67.0	8.5	18.0		0.25				17,000	33,000	16	60
	72.0	11.0	22.0		1.00				20,000	36,000	18	65
Leaded Tin Bronze:												
89S	86.0	7.0	2.0		0.25				20,000	40,000	30	70
	89.0	9.0	4.0		0.75				23,000	45,000	25	75
3	85.0	7.5	0.5	2.5	0.50				20,000	40,000	28	70
	89.0	9.0	1.5	5.0	1.00				24,000	48,000	20	75
Leaded Semi-Red Brass:												
87	76.0	2.3	7.0	6.0	1.50				15,000	34,000	26	55
	83.0	3.5	10.0	8.0	2.50				17,000	39,000	28	60
Manganese Bronze:												
100	55.0	Max.	Max.		Max.	0.50	0.50	0.25	32,000	75,000	30	
	60.0	1.0	0.5	bal.	0.80	2.00	2.00	1.50	38,000	80,000	22	115-150
150	60.0	Max.	Max.			2.00	3.50	2.50	50,000	97,000	25	
	68.0	0.2	0.2	bal.		4.00	5.00	5.00	53,000	100,000	20	170-195
200	60.0	Max.	Max.			2.00	3.50	2.50	70,000	119,000	18	
	68.0	0.2	0.2	bal.		4.00	7.00	5.00	80,000	124,000	14	200-230
Aluminum Bronze:												
104-AB	Min.					3.00	10.00		34,000	88,000	14	
	83.0					5.00	11.00		37,000	90,000	18	155-190
115-N	Min.				3.00	3.00	10.00	Max.	45,000	100,000	8	
	78.0				5.00	5.00	11.50	3.50	50,000	110,000	8	180-210



1. Statically Cast In Sand
Note large grain structure due to slower cooling.



2. Centrifugal Casting
Note equiaxed and smaller grain structure



3. Forging
Note directional orientation of grain structure

Fig. 14-1. Photomicrographs showing considerable variation in grain structure and physical properties.

FERROUS METALS

Steel, when centrifugally cast in permanent molds, has appreciably increased physical properties. The photomicrographs in Figures 14-1 and 14-2 are presented as an illustration of the type of structure that is obtained when castings are made centrifugally.

It can be seen that the much finer grain size of the centrifugal casting exists when the centrifugal casting is cast against a metal mold rather than a sand mold. This almost invariably results in the centrifugal casting having higher tensile properties as well as better elongation and impact properties. (See Tables 14-2 and 14-3.)

BI-METALLIC (ROLLING MILL ROLLS)

The centrifugal casting process has been developed for the production of rolls for hot and cold metal forming mills. The type of machinery needed is covered in Chapter 2: Types of Machines. These rolls require a hard wear resistant surface on the outside of the roll and a strong, tough, machinable material for the roll necks as well as the main body of the roll.

Table 14-2.
Properties of Cast Steel

Casting method	Heat treatment deg. F	Elastic limit lb/in. ²	Tensile strength lb/in. ²	Elongation 2 in. %	Reduction area %	Brinell hardness
Centrifugal	Normalized	47,000	85,000	21.0	35.0	160
Sand	Normalized	44,000	87,000	18.0	28.0	160
Centrifugal	1500 oil quench, 950 draw	136,000	140,000	7.0	14.0	302
Sand	950	135,000	144,000	6.0	13.3	302
Sand	850	142,000	148,000	5.0	14.6	321
Centrifugal	800	166,000	180,000	3.0	5.3	364
Sand	800	150,000	166,000	2.0	5.3	364
Sand	425	192,000	199,000	1.5	3.6	430
Centrifugal	355	212,000	218,000	.75	3.0	477
Sand	355	207,000	221,000	.5	3.0	477

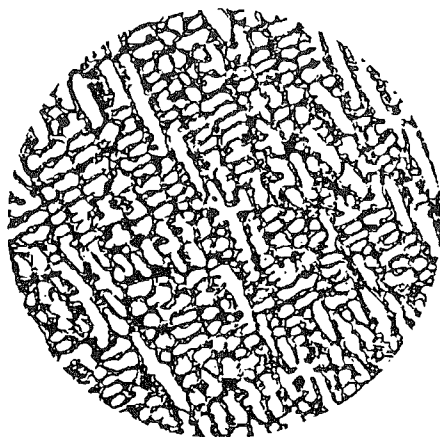


Fig. 14-2a. Photomicrographs showing enhancement in grain structure gained by centrifugally casting (left) as opposed to conventional sand casting (right) of stainless steel. (200X)

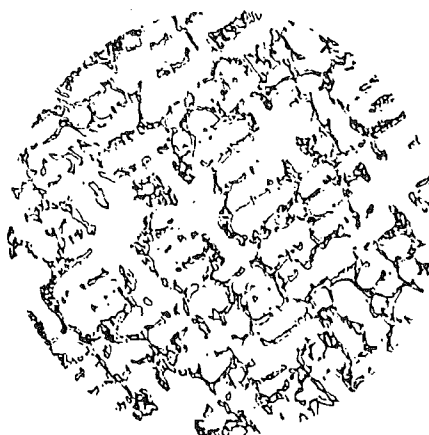


Fig. 14-2b. Photomicrographs showing enhancement in grain structure gained by centrifugally casting (left) as opposed to conventional sand casting (right) of mild steel. (200X)

Review of Static Method

The method used for many years to produce bi-metal rolls was a static casting process. In the static casting method, a mold was made up of several sections of sand and partly of large metal chills. These sections were assembled in a deep pit so the roll could be made standing on end. First, the mold was filled with the hard wear-resistant metal and

left to solidify for an experimentally predetermined time. This would permit a shell to solidify to the desired thickness against the chill portion of the mold. At the end of this time, the soft core metal was poured into the mold displacing the liquid hard metal. This method required the same amount of the hard metal (usually an expensive alloy) to be melted as the back-up (flush) metal. While the technique has been developed to consistently produce very good rolls, it was expensive and comparatively slow in production.

Table 14-3.
A Comparison of Properties of Sand Cast Ni Hard and Centrifugally Cast

IRONS

Chemical Analysis and Properties of Ni-Hard

	Type 1—Regular		Type 2—Hi-Strength	
Chemical Analysis				
Total Carbon.....	3.00-3.60		2.90 Max.	
Graphitic Carbon.....	0.10 Max.		0.10 Max.	
Silicon.....	0.40-0.70*		0.40-0.70*	
Manganese.....	0.40-0.70		0.40-0.70	
Sulfur.....	0.15 Max.		0.15 Max.	
Phosphorus.....	0.40 Max.		0.40 Max.	
Nickel.....	4.00-4.75		4.00-4.75	
Chromium.....	1.40-3.50		1.40-3.50	
*Silicon content may exceed 0.70% in light sectioned or gray-backed castings.				
Engineering Properties ¹	Sand Cast	Chill Cast	Sand Cast	Chill Cast
Brinell Hardness, minimum ²	550	600	525	575
Rockwell C Hardness, minimum.....	53	56	52	57
Trans. Strength, 1.20" diameter test bars, 12" span (lbs.).....	4000-5000	4500-6800	4500-5500	5500-7000
Trans. Defl., 1.20" diameter test bars, 12" span (in.).....	.080-.110	.080-.120	.100-.120	.100-.120
Tensile Strength psi, 1.20" diameter test bars.....	40-50,000	50-60,000	45-55,000	60-75,000
Modulus of Elasticity, million psi.....	24-26	24-26	24-26	24-26
Izod AB Impact, ft. lbs. ³	20-30	25-40	25-35	35-55
Pattern Shrinkage, in. per ft.....	$\frac{5}{32}$ – $\frac{1}{4}$	$\frac{5}{32}$ – $\frac{1}{4}$	$\frac{5}{32}$ – $\frac{1}{4}$	$\frac{5}{32}$ – $\frac{1}{4}$
Specific Gravity.....	7.60-7.80	7.60-7.80	7.60-7.80	7.60-7.80
Density, lbs. per cu. in.....	.275-.280	.275-.280	.275-.280	.275-.280
Thermal Coefficient of Expansion, millionths per °F.				
50—200°F.....	4.5-5.0	4.5-5.0	4.5-5.0	4.5-5.0
50—500°F.....	6.3-6.6	6.3-6.6	6.3-6.6	6.3-6.6
50—800°F.....	6.8-7.1	6.8-7.1	6.8-7.1	6.8-7.1
Electrical Resistivity, microhm-centimeters, 78°F.....	80	80	80	80
Thermal Conductivity				
Cal./cm sec. °C—120°F.....	.034	.034	.034	.034
450°F.....	.045	.045	.045	.045
Magnetic Properties.....	Fully Magnetic		Fully Magnetic	
Fracture ⁴	White		White	

(¹) All the above properties are for Ni-Hard stress relieved 4 hrs. at 400°F.

(²) Determined on 2 x 6 x 6" test blocks, using tungsten carbide Brinell ball.

(³) 1.20" diameter unnotched bar, struck 3" above support.

(⁴) Graphite-free Ni-Hard possesses maximum physical properties and abrasion resistance, hence a white fracture should be specified. Heavy castings, such as rolls or roll heads, are often cast with a chilled, white working surface and a gray backing to permit limited machining.

The Centrifugal Method

The technique used for the production of the centrifugally cast rolls varies somewhat from foundry to foundry. Even the name given to the rolls varies from 'Spin Cast' to 'Schleuderguss,' etc. The rolls are made in both horizontal machines as well as vertical machines. Both techniques are used to produce high quality rolls much more economically than the static casting method. The centrifugal casting method has become the world standard.

The centrifugal casting method requires melting only a relatively small quantity of the shell metal. This can be done in an electric induction furnace very economically, as only the approximate required amount of metal has to be melted, which saves in electricity as well as alloy costs. The back-up or core metal is also melted in an induction furnace. Very little pigging of the shell metal is required as it is wholly used in the cast roll.

The centrifugal casting machine for bi-metallic rolls is used as follows: If only a sleeve is to be produced, the pre-heated 'body' chill is placed onto the casting machine. An insulating ceramic coating is applied to the interior mold surface while the mold is spinning. Then, while the mold is still spinning, a weighed quantity of the specified metal composition is poured and spun until the molten metal has solidified.

If a complete roll is to be produced, the above procedure is followed. After the spinning has been completed and the machine has come to a stop, the mold is picked up by a crane, turned from the horizontal to the vertical position and placed on a pre-assembled drag portion of the mold, which is located in a pit. A cope is placed on the centrifugal mold and metal is poured directly down through the opening in the cope or through a snorkel protruding through the cope. The snorkel is gradually withdrawn from the mold as the level of the metal rises in the mold. If a vertical casting machine is used, the same procedure may be followed. In some cases, the entire mold-cope-cheek-drag may be spun to form the shell, and the back-up metal may be poured without removing the mold from the machine. However, in a horizontal machine the mold assembly is rotated to a vertical position and placed in a pit before pouring the back-up metal. Vertical centrifugal casting machines are considerably more expensive to manufacture and install.

The overall process for producing a centrifugally cast roll appears to be a very simple operation. However, many of the details are quite exacting, such as mold temperature, mold coating material, mold spraying equipment, pouring spout design, spinning speed, delay time between pours, and mold design.

Constant developmental work is pursued by each foundry to produce higher quality rolls at reduced cost. Each foundry has developed its own analysis presently used for the core metal as well as the shell metal. Table 14-4 presents some of the mixtures used for the shell metal.

The economical production of bi-metallic centrifugal castings and the wide range of metals and alloys that can be used has considerably enlarged the market for roll found-

Table 14-4.
Shell Metal Mixtures

Types	Major alloys used
Alloy chilled iron	3.30/3.60 carbon plus chromium, nickel, and molybdenum
Modified ni-hard (nickel grain iron)	4.50 nickel, 1.60/1.80 chromium
Alloy steel or adamite	1.20/1.60 carbon
High chromium iron	2.5/3.00 carbon, 12-20% chromium
Spheroidal graphite iron	3.50/4.50 nickel

ries. The same foundries can utilize their machines to produce the following:

- Work rolls for hot and cold strip mills
- Ring type rolls for forming and reducing
- Back-up roll sleeves
- Small rolls or sleeves for rolling rod or merchant shapes

Roll Metallurgy

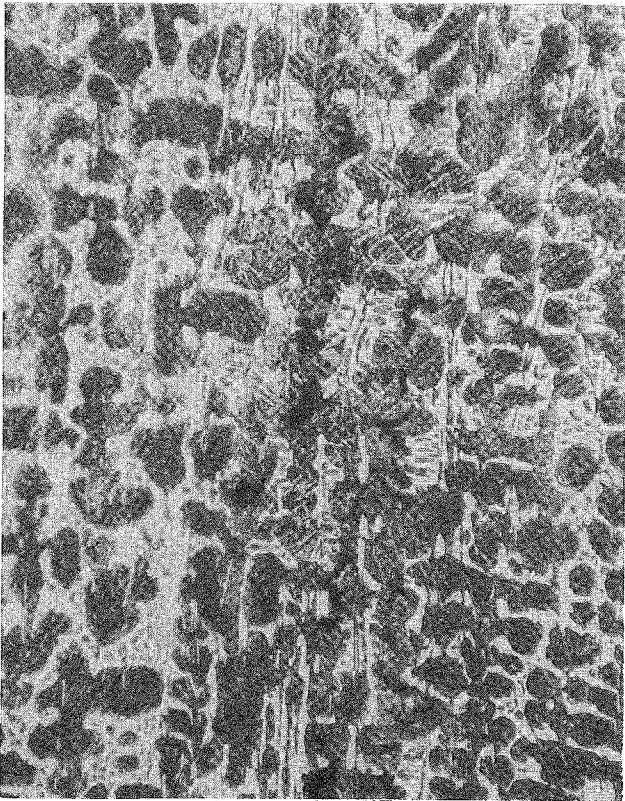
In a comparison between centrifugally cast rolls and those statically cast, it is found that centrifugally cast rolls have:

- Appreciably better mechanical properties
- A high degree of shell uniformity of composition (Fig. 14-3)
- Increased density
- A noticeable decrease in the presence of detrimental slag particles
- Increased tensile strength; for example: Ni-Hard has 10% increased tensile strength
- Better controlled stress patterns from the surface of the roll to the center
- Increased ability to withstand thermal gradients along with greater impact capabilities
- Greater uniformity of the microstructure of the shell material throughout its thickness
- Greater uniformity of the hardness in the shell from the rolling surface to the core metal

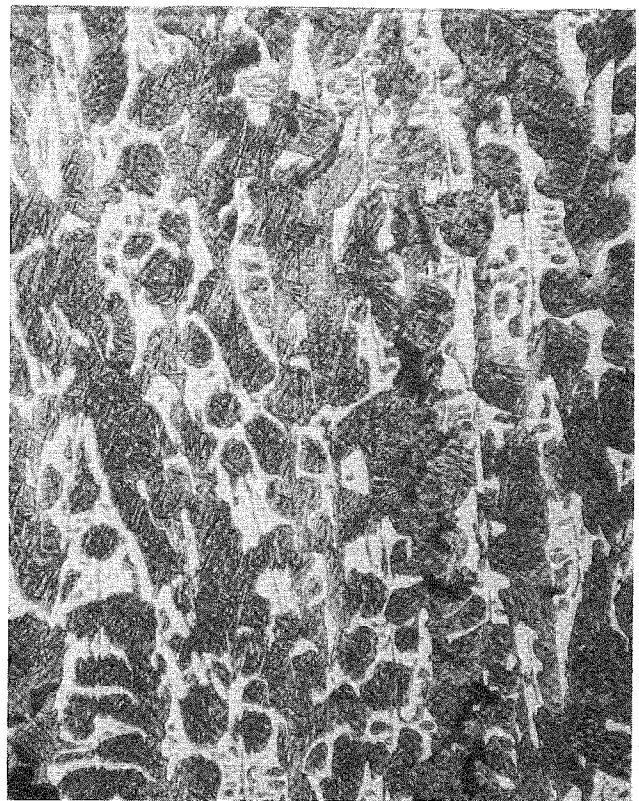
Roll Microstructure

The microphotographs of an actual roll (Fig. 14-3) graphically illustrate a direct comparison of the same metals statically cast and centrifugally cast. This comparison is particularly important as they are taken from rolls and not test bars. There is a noticeable change in the microstructure of the statically cast roll shell at increased depth from the surface, whereas the centrifugally cast roll is practically uniform in microstructure at all depths!

Modified Ni Hard (Static Cast)



.25 inch from surface



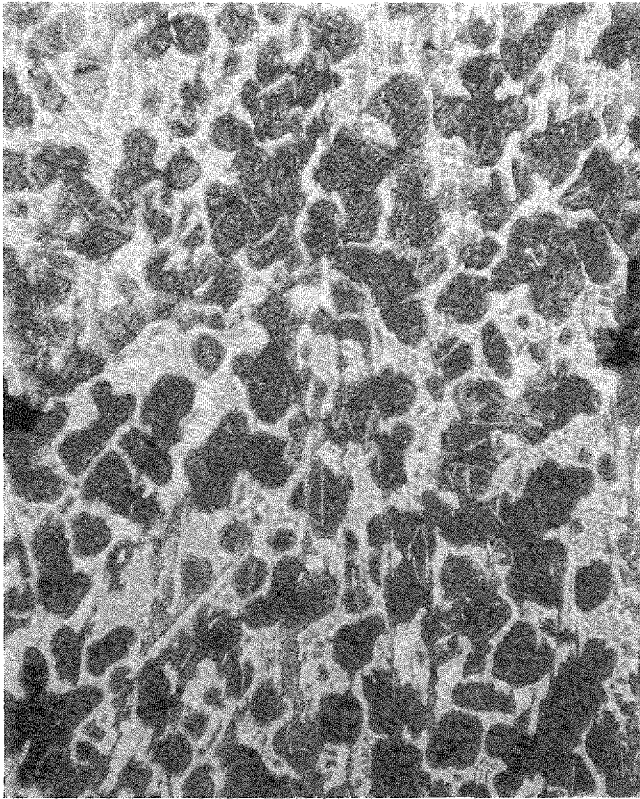
.75 inch from surface



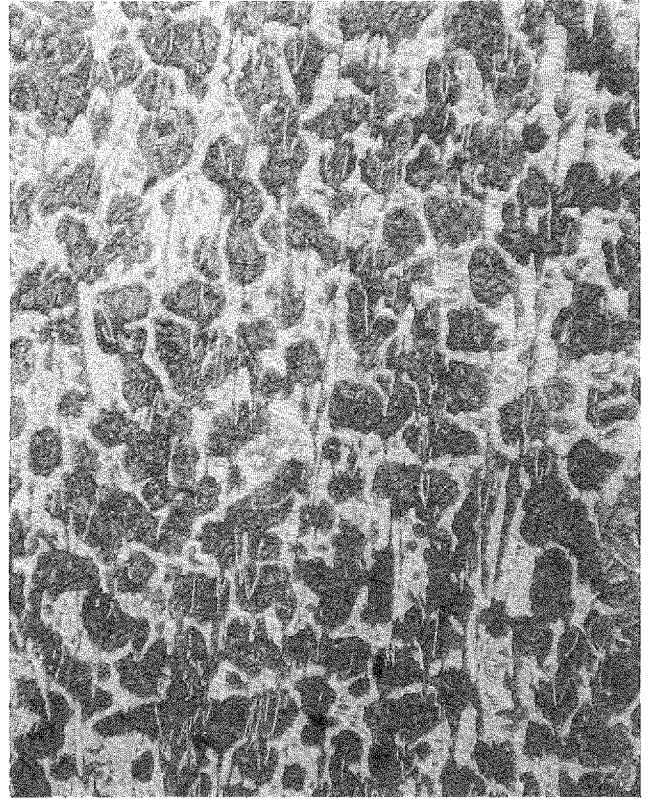
1.25 inch from surface

Fig. 14-3. Photomicrographs showing roll microstructure of static versus centrifugal casting.

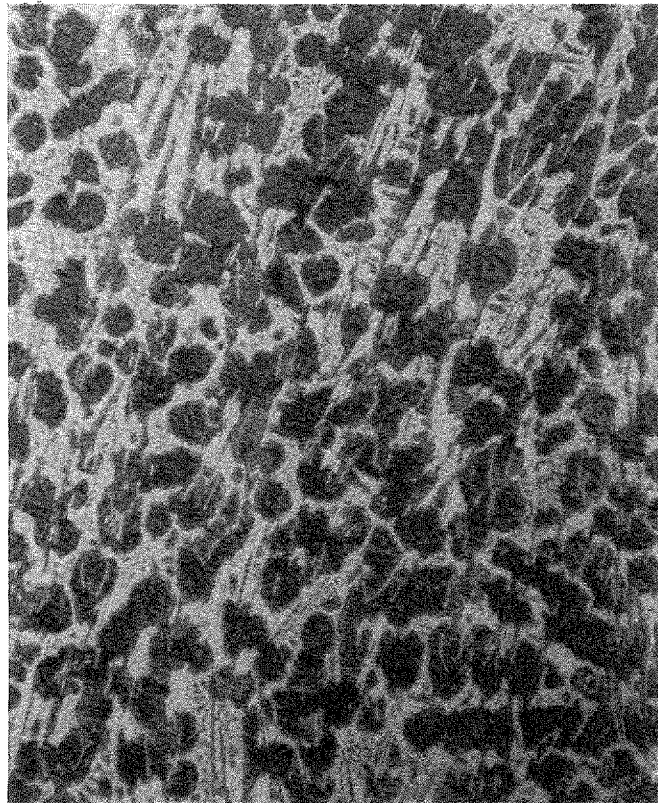
Modified Ni Hard (Centrifugally Cast)



.25 inch from surface



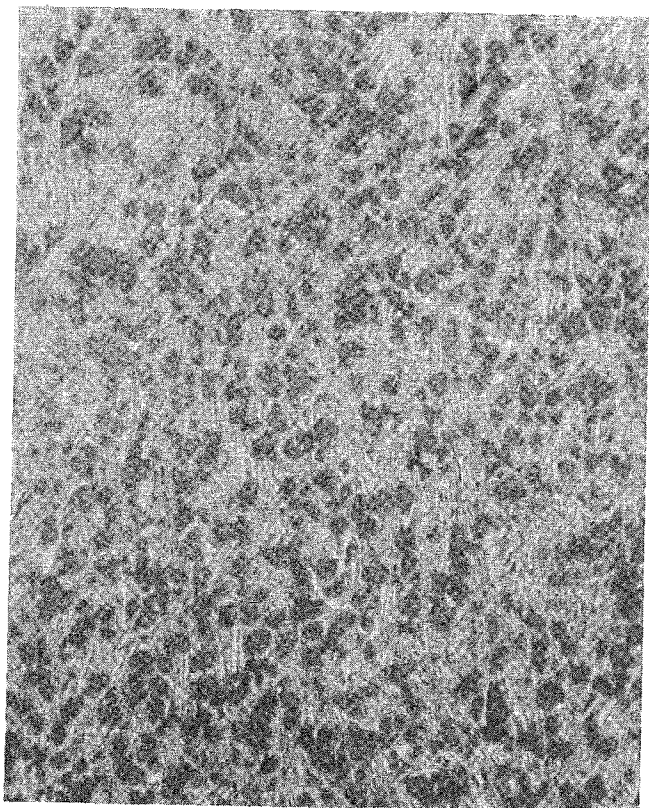
.75 inch from surface



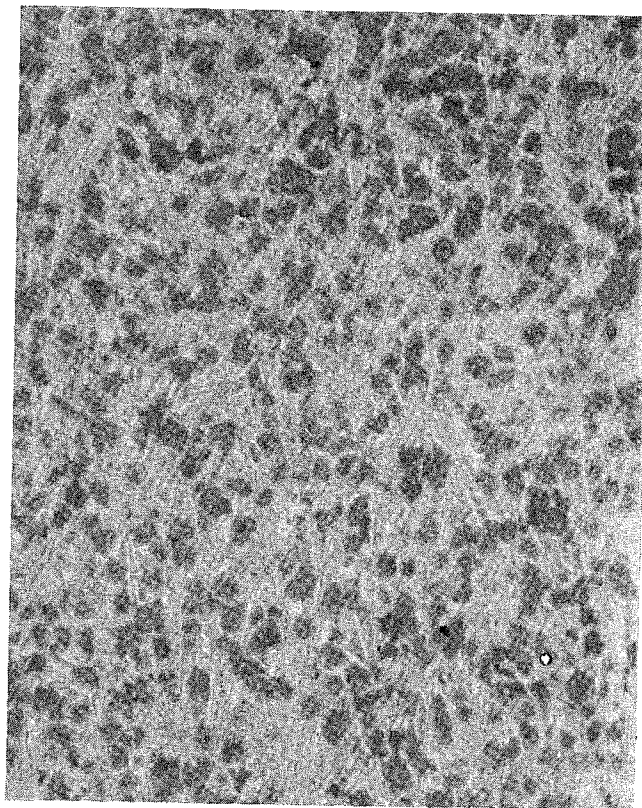
1.25 inch from surface

(Fig. 14-3 continued)

High Chromium Iron (Centrifugally Cast)



.25 inch from surface



.75 inch from surface



1.25 inch from surface

(Fig. 14-3 continued)

Precision Centrifugal Casting

INTRODUCTION

Precision casting is a very old process, going back more than a thousand years. In recent times, it has been used for the production of jewelry and dental inlays. During WWII, knowledgeable people in the jewelry workshops applied their technique to the production of non-precious metals, casting steel, alloy steel, and stainless steel parts for the US Army. Precision casting is very suitable for the production of small, accurately as-cast parts required in small quantities, in a short length of time, with very little tooling.

The precision centrifugal casting method involves starting with a model or pattern, which may be very intricate. It may even involve backdraft, which would inhibit the production of the part by customary foundry methods. The model is made slightly oversized to make allowances for the various shrinkages that may occur. These shrinkages might appear in the variable molding materials—rubber (rubber molding), the investment material, or the metal being cast.

To begin the process, a suitable rubber or rubber-like material is placed about the model and then vulcanized, or otherwise processed, to make the material permanently assume the shape of the model it encompasses. The rubber is then cut with a sharp knife in as few pieces as possible to remove it from about the model. The internal cavity of the rubber mold now has the exact contour of the model.

The rubber cavity is filled with molten wax (or a suitable plastic). After the wax has solidified, the rubber mold is removed, leaving a replica of the model in wax. The wax models are assembled in clusters with tubes made of the same wax. The clusters are suspended inside a flask (Fig. 15-1) about 6 in. (152 mm) in diameter by 10–12 in. (254–305 mm) long. The size of the flask might vary from 2 in. (25 mm) to 12 in. (305 mm) or larger in diameter (Fig. 15-2).

“Investment” material in the form of a slurry is poured into the flask and permitted to solidify. The slurry is in the form of a refractory cream so that, with some vibration, it will completely surround the wax models with no entrained air bubbles. After the slurry has been permitted to solidify, the flask is heated to a high temperature (as high as 1800°F/982°C in some cases) and the wax is melted out.

Depending upon the type of centrifugal casting machine being used (Fig. 15-3), one (or more) of these hot flasks is put into the machine. Molten metal is then poured into the flask cavities by one of the various methods preferred by the particular foundry. Because the metal solidifies very rapidly, the spin time is very short (1 minute, more or less). After the flasks cool, the investment material is broken up and removed, leaving a casting of the desired size and surface finish.

The smooth, accurate castings can be produced in large clusters in one flask and four flasks may be poured into at one time. Subsequent machine work might be required to ream holes, etc., as necessitated by the particular part, but usually about 95% of the machine work is eliminated. The results are a great savings in time and cost of manufacture. Depending on the metal being cast, parts as thin as 0.015 in. may be cast with an accuracy of a few thousandths of an inch per inch of length.

The speed of rotation is not critical as the centrifugal force is primarily utilized to move the molten metal to completely fill the mold cavity. Usual practice is to use a peripheral speed of 500–1000 ft/min based upon the average diameter of the arrangement of the castings in the machine.

Many variations of the techniques employed in every stage of the process, as well as the materials used, have been developed.

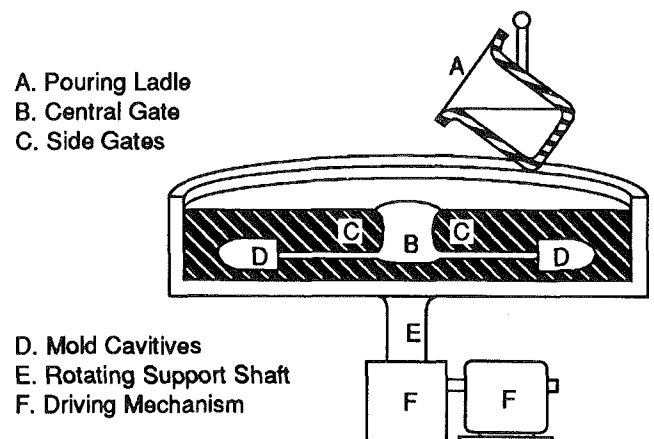


Fig. 15-1. Sketch of centrifugal unit for precision casting.

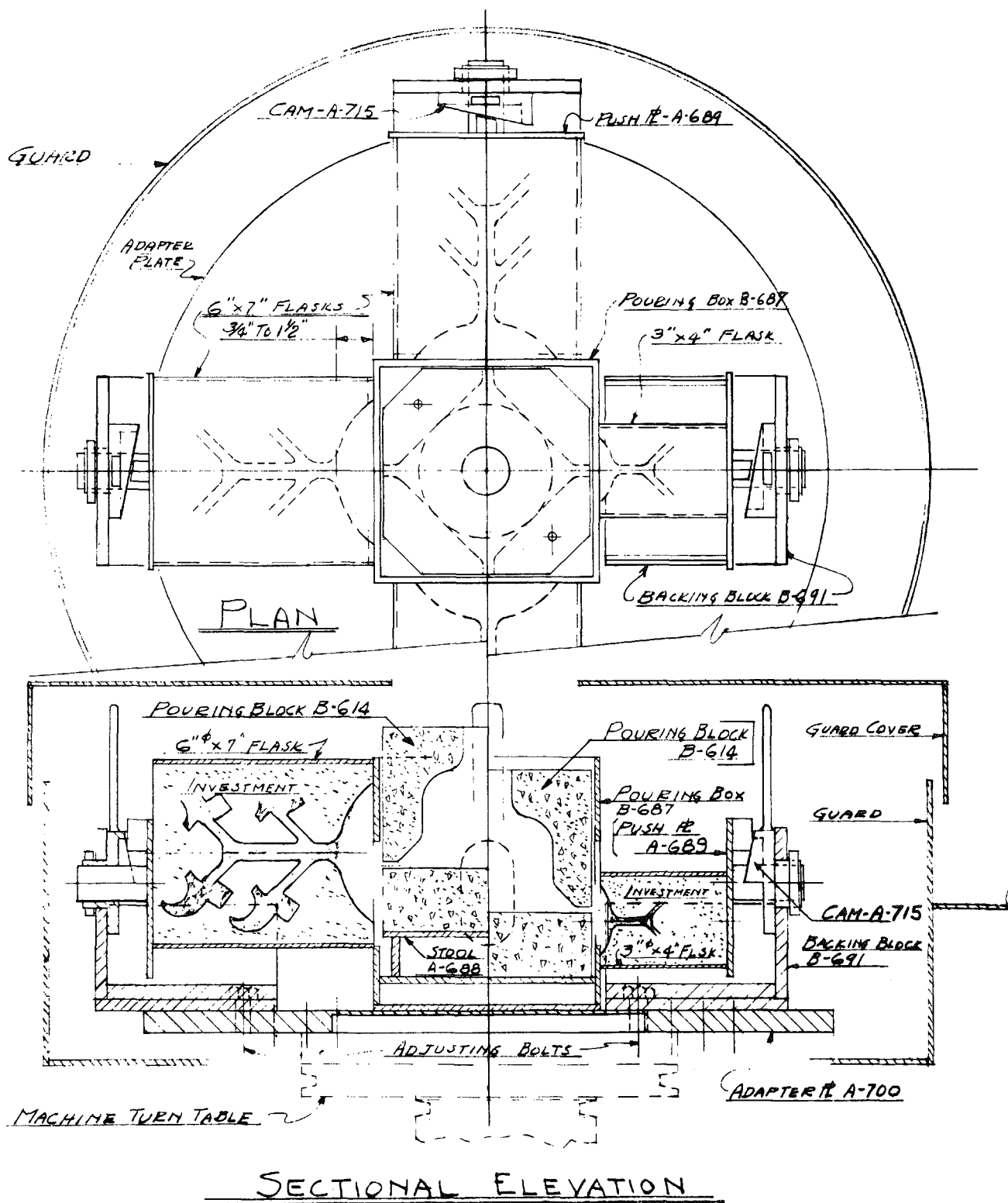


Fig. 15-2. General assembly of investment molds and fixture.

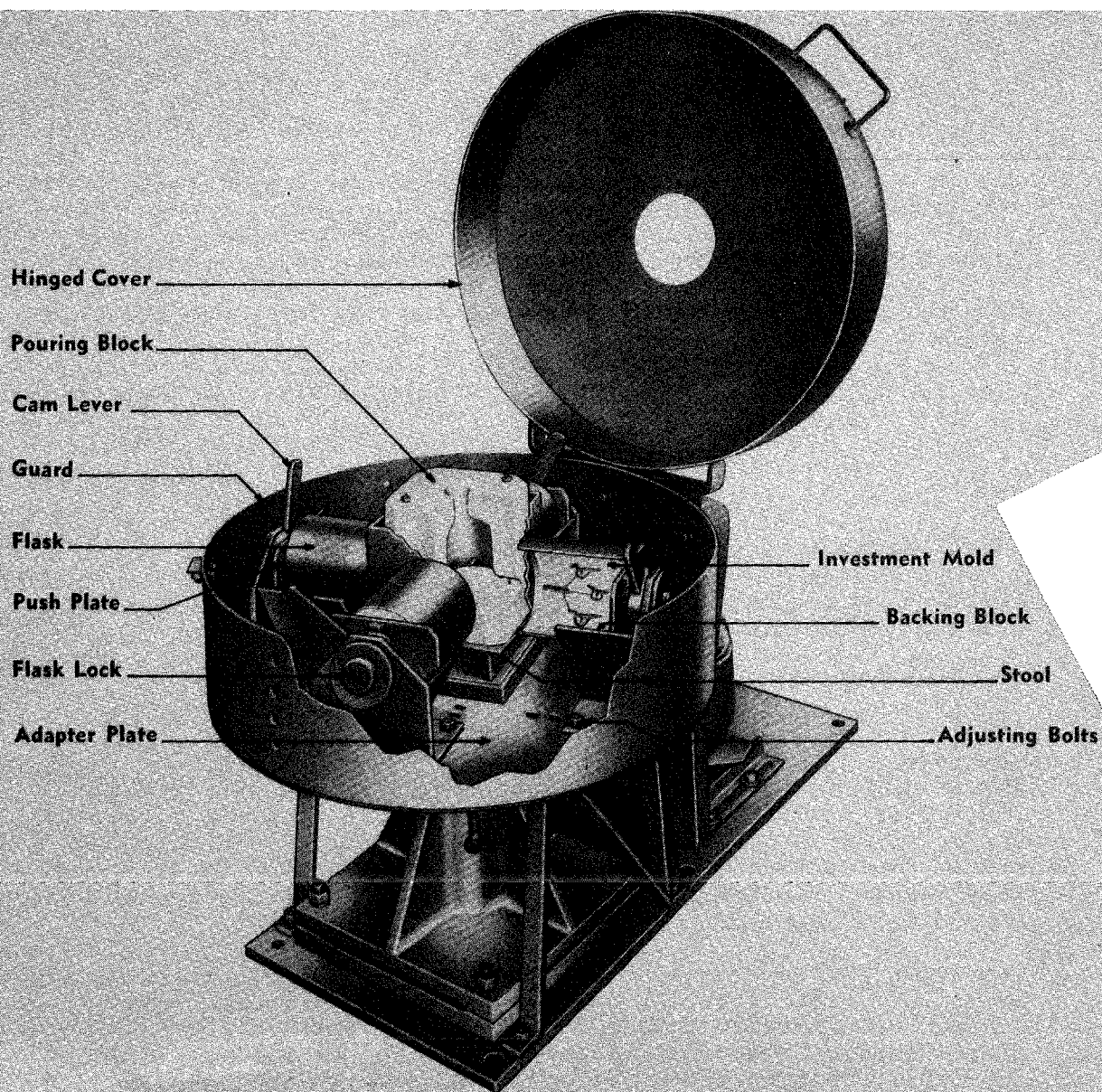
(Fig.15-2. Continued.)

PREPARATION OF FIXTURE

1. Fixture is designed to accommodate Flasks from three to six inches in diameter and four to seven inches long. Flasks of different lengths are accommodated by placing in proper holes the adjustment bolts holding Backing Blocks (B-691) onto Adapter Plate (A-700).
2. Flasks of different sizes are not to be used in this fixture during any one cast or pouring.
3. Place Pouring Block (B-614) in Pouring Box (B-687).
4. When five-inch or larger diameter Flasks are used, use Stool (A-688) in Pouring Box (B-687).
5. Heat Pouring Block to temperature of about 1000-1800F before making the first of a series of pourings.

OPERATION

1. Place Flasks in position in Backing Blocks (B-691).
2. Secure them in place by turning Cam Lever (A-690) to right. Cam must be jammed tightly against Push Plate (A-689).
3. Start machine and allow to come up to speed (375 RPM approximately).
4. Pour very rapidly into Pouring Block a weighed quantity of metal. The amount of metal should be sufficient to fill entirely all of the molds, including sprues and gates, and a moderate surplus in the mouth of the mold. The metal should "squirt" into each of the molds simultaneously through small openings shown opposite each mold between top and bottom halves of Pouring Block, and molds should fill rapidly.
5. When openings in Pouring Block are too small, they may be enlarged by using a small round file. If openings have become enlarged by erosion or otherwise damaged, they may be repaired and made to proper size by use of refractory clay or other suitable plastic material. Pouring Block may be taken apart for occasional cleaning, as required. Otherwise, do not remove Block from fixture between pourings.
6. Stop machine, remove Flasks, and repeat operation.



These machines are supplied complete with a 2 HP motor and starting switch. A model providing continuously variable speed can be supplied if desired. The rapidity with which flasks can be loaded and unloaded results in high production rates, and makes possible the economical, low-cost production of precision castings.

Fig. 15-3. Precision centrifugal casting machine.

De Lavaud Process

Of the many varied centrifugal casting systems, the casting process producing the largest tonnage of centrifugally cast product is the De Lavaud system, named for Dmitri De Lavaud, a Brazilian, who developed the process in the 1920s.

The De Lavaud process is used for producing cast iron pressure pipe. The casting machine consists of a cylindrical steel mold surrounded by a water jacket and is mounted on rollers (or supported with large bearings), so that it can be rotated within the water jacket. The entire assembly, jacket and mold, can be moved longitudinally to the axis of the mold, on a fixed bed, inclined slightly from the horizontal (Fig. 16-1).

The pouring trough has a pivoted ladle at one end and a small curved spout at the other. The spout directs the molten metal in the trough toward the side wall of the mold in the direction the mold is rotating where it is picked up immediately via frictional contact with the mold. The ladle is tilted mechanically at a uniform rate to pour a constant measured stream of metal (enough for one pipe) into the trough.

The mold-jacket assembly is retracted at such a rate that an even helix of molten iron is laid upon the rotating mold with a slight overlap to ensure good fusion. The rotation and pour is rapid enough so that the previous spiral has not solidified before another spiral is placed next to it. A combination of rotational (centrifugal) and retractive motion of the mold maintains a smooth, even cylindrical shape on the inside surface of the pipe. The speed of rotation must be rapid enough to prevent any slipping (raining or sagging) between metal and mold. Metal delivery is accurately linked to traverse speed, so control is not lost over pipe length and thickness.

The trough is fully exposed; available for the operators to remove the thin ribbon of metal, known as the splinter, left in the trough.

On this type of machine the socket core is usually retained by a metal plate held in position by a number of tapered wedges knocked in by hand. After casting, the mold has to cease rotating, the wedges have to be knocked out, then the plate must be removed and a puller inserted. In the

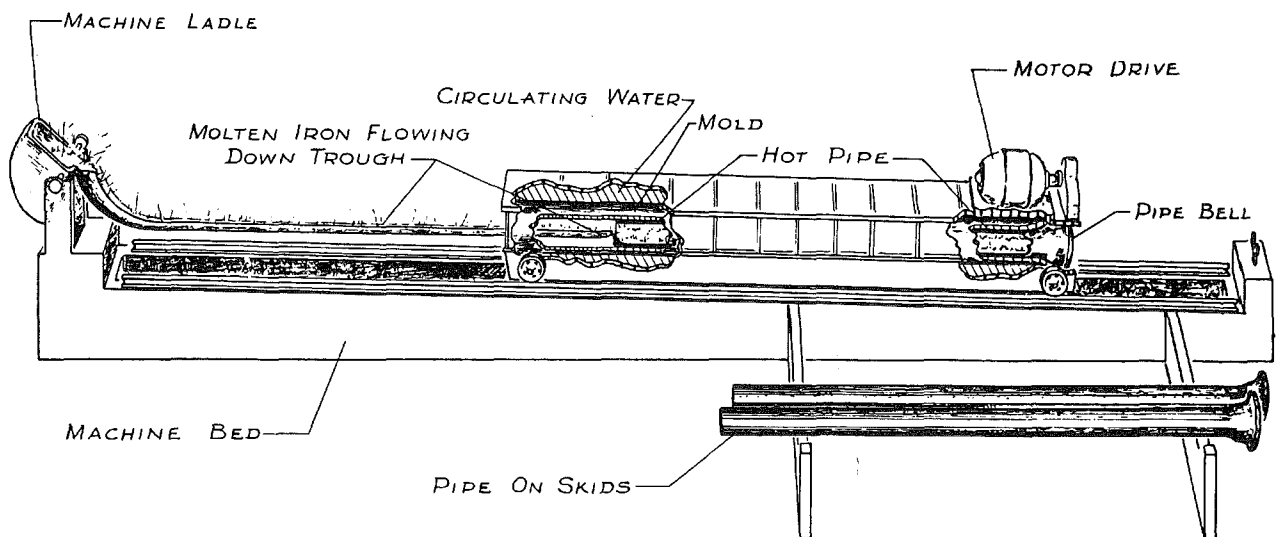


Fig. 16-1. Casting machine for pipe centrifugally cast in metal molds.

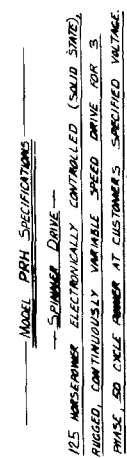


Fig. 16-2. Pressure pipe machine.

smaller diameters, this puller is a type of scissor tong which is pushed through the core and then attached to a block anchored on the bottom end of the machine platform. The machine then moves up the track leaving the pipe anchored at the bottom. Afterward, the pipe is removed from the centerline of the machine and the machine returns to the bottom position, where the core for the next pipe is placed into position. The ladle is refilled with molten metal, while the machine returns to the top of the track, ready for casting the next pipe (Fig. 16-2).

It is always desirable to remove the pipe from the mold as soon as possible after solidification. The reason for this is partly to avoid energy loss before heat treatment and partly to minimize thermal damage to the mold. In the four-stroke cycle of operation it is necessary to remove splinters and to apply a wash to the pouring trough. The core has to be loaded when the machine is in the bottom position. In the more modern method, elimination of these requirements enables a two-stroke operation to be carried out with a very considerable increase in productivity. Most modern machines are similar to those shown in Figures 16-3 and 16-4.

The essential differences between this modern two-cycle and the conventional four-cycle machine are:

- the use of roll-over troughs and fall chutes, and of trough shifters using twin troughs
- the use of automatic core loader/retainers (Figs. 16-3 and 10-3)

The core loader is a completely automatic device. In addition to placing the core, the mechanism keeps it in place until the loader/retainer swings out of position to allow the pipe extractor to operate. This too is operated from a control console. Referring to Figure 16-3, *b* shows the end of the casting stroke with the extractor moving into position to anchor the pipe; *c* shows the rollover chute and trough in the inverted position, thus allowing the splinter to fall out; and *d* shows the pipe being extracted by the machine moving up the track as before, but, because the trough has been emptied of solidified metal in a short space of time and blacking of the trough is now required very infrequently, the time interval between casting and pipe removal is considerably reduced.

Another device developed to deal with the trough problem in Figure 16-3 *e* is a trough shifter. This device has two troughs, which are used alternately, thus enabling each trough, in turn, to be available for cleaning and blacking without holding up the casting cycle.

The De Lavaud process is limited in that the bell and bell core can be placed only at one end in order for the tube to contract freely in longitudinal axis. The process is also limited to alloys that flow well, such as gray and ductile iron, and that will not severely erode the refractory trough.

The principal drawback is the rapid cooling of the casting, via the water-cooled jacket, requiring subsequent annealing. A popular modification was the Super De Lavaud process, in which the metal was cast chill-free by using a special coating applied by compressed air.

The DeLavaud process sometimes causes a defect known as laces; a slight helical discontinuity on the outside surface of a pipe, usually containing undissolved silicon. It is caused by turbulence of iron flow into the mold due to trough vibration, as well as excess silicon in the coating of the mold.

Generally speaking, a refractory mold coating is not used in the De Lavaud process. However, if a refractory mold coating is used, it is applied before casting by a nozzle positioned so as not to interfere with the operation. When the mold is at the extreme upper end of the fixed bed, it is ready for casting. At this time the trough extends down the barrel of the mold for nearly its full length. During casting the rotating water-jacketed mold travels longitudinally down the bed as the metal flows tangentially onto the thin layer of powdered inoculant where it is held in place by centrifugal force until solidified, at which time the mold is stopped and the casting removed by anchoring it to the puller block and withdrawing the mold. The process is then repeated. If a refractory mold coating is used, the powdered inoculant is not used.

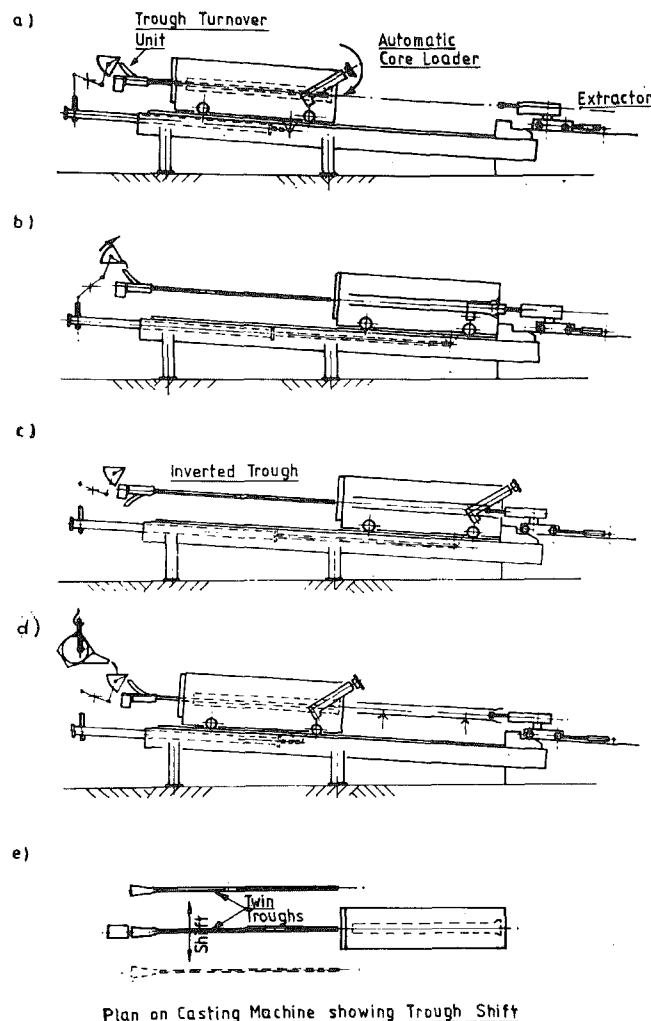
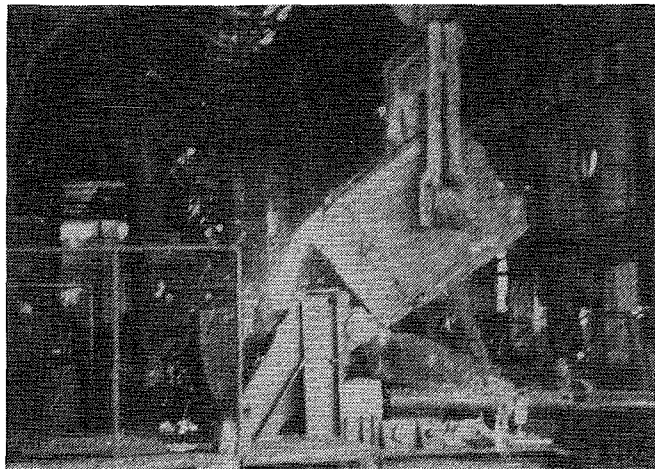
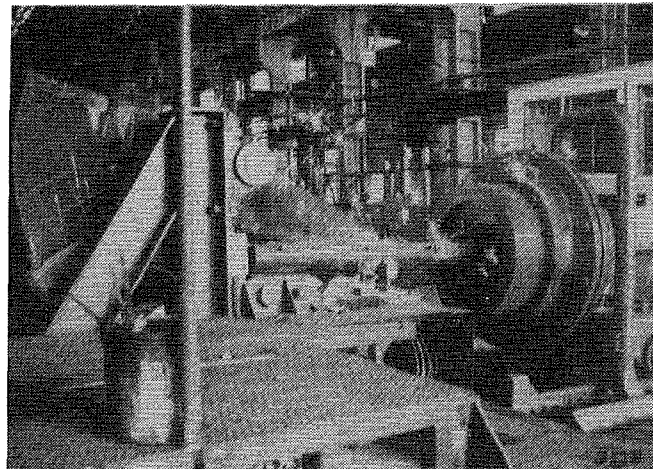


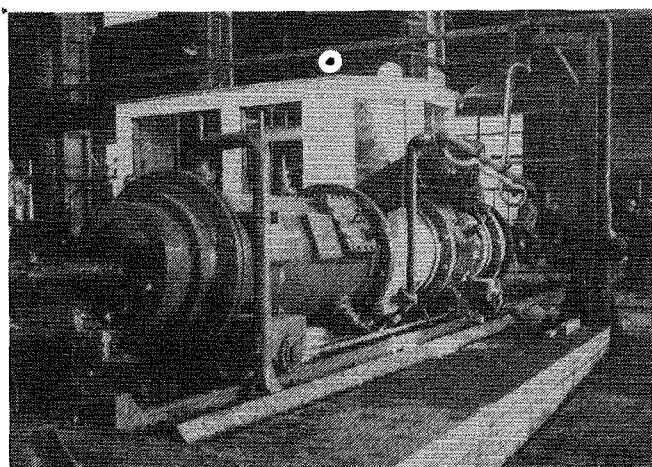
Fig. 16-3. Modern pipe spinning machine with automatic core loader and full-length extractor.



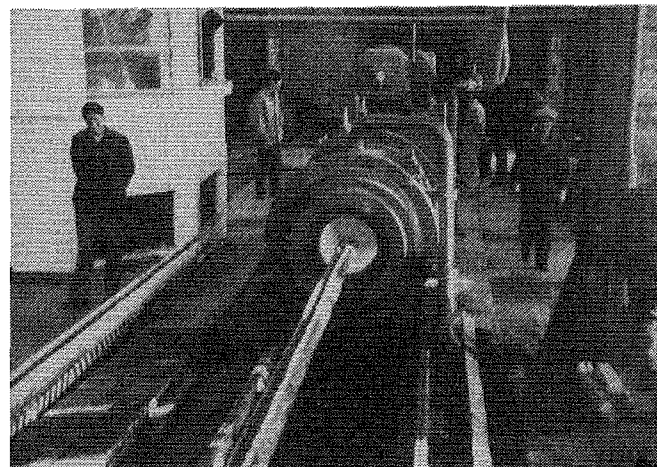
Filling the casting machine ladle.



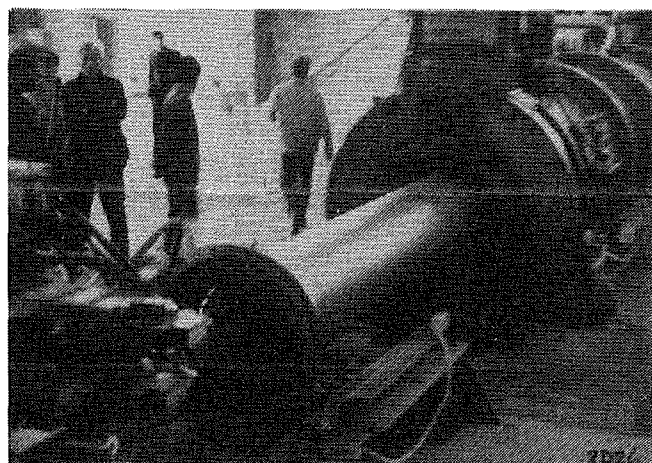
Start of casting operation.



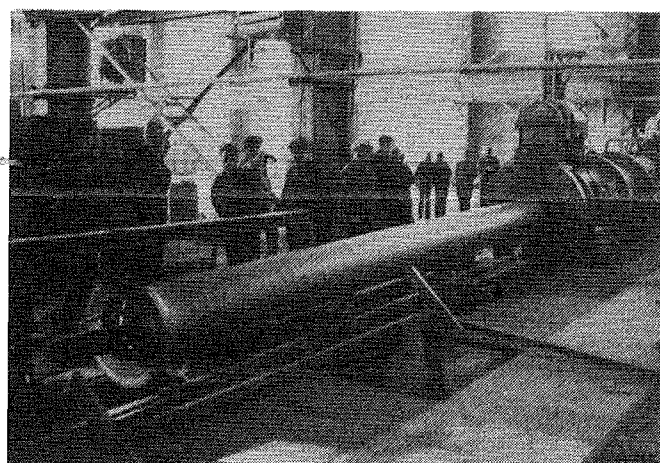
Pipe casting.



Completion of pouring.



Pipe extraction.



Cast pipe, dia. 400mm x 6m.

Fig. 16-4. Model PRH ductile iron pipe casting machine.

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