Dec. 19, 1961 H. R. SMITH, JR 3,013,315

APPARATUS FOR CENTRIFUGAL CASTING

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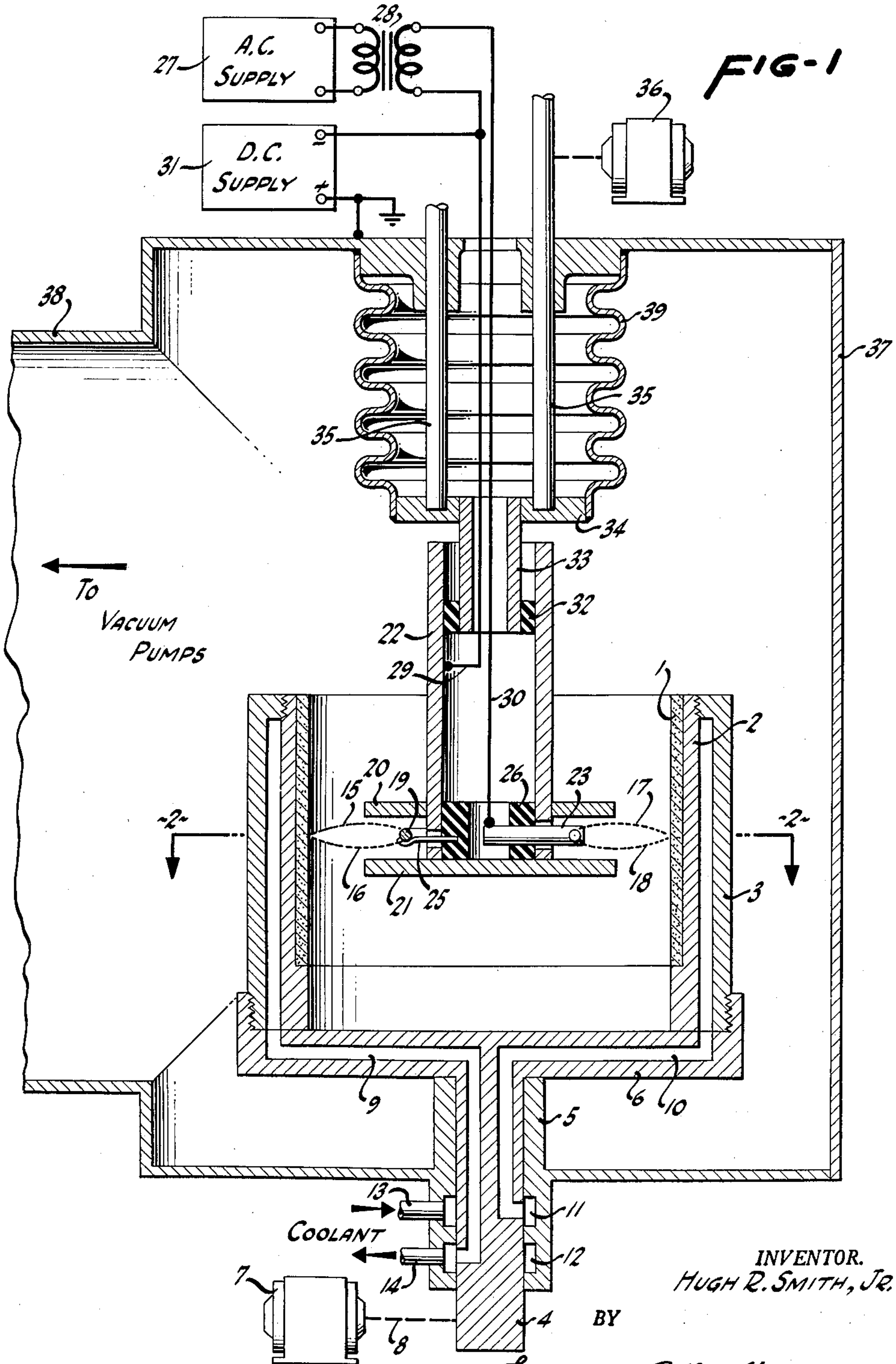

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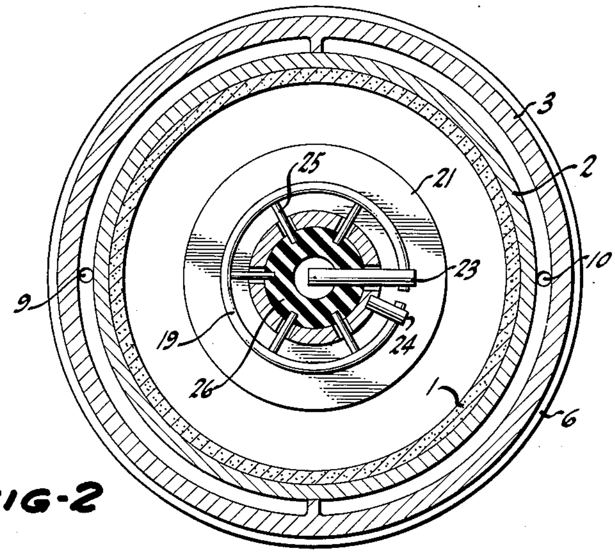

FIG-2

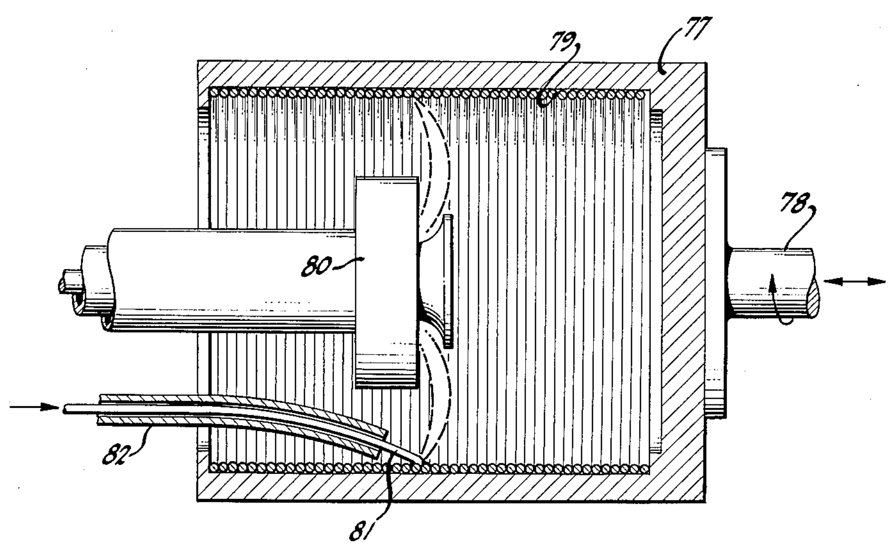

FIG-5

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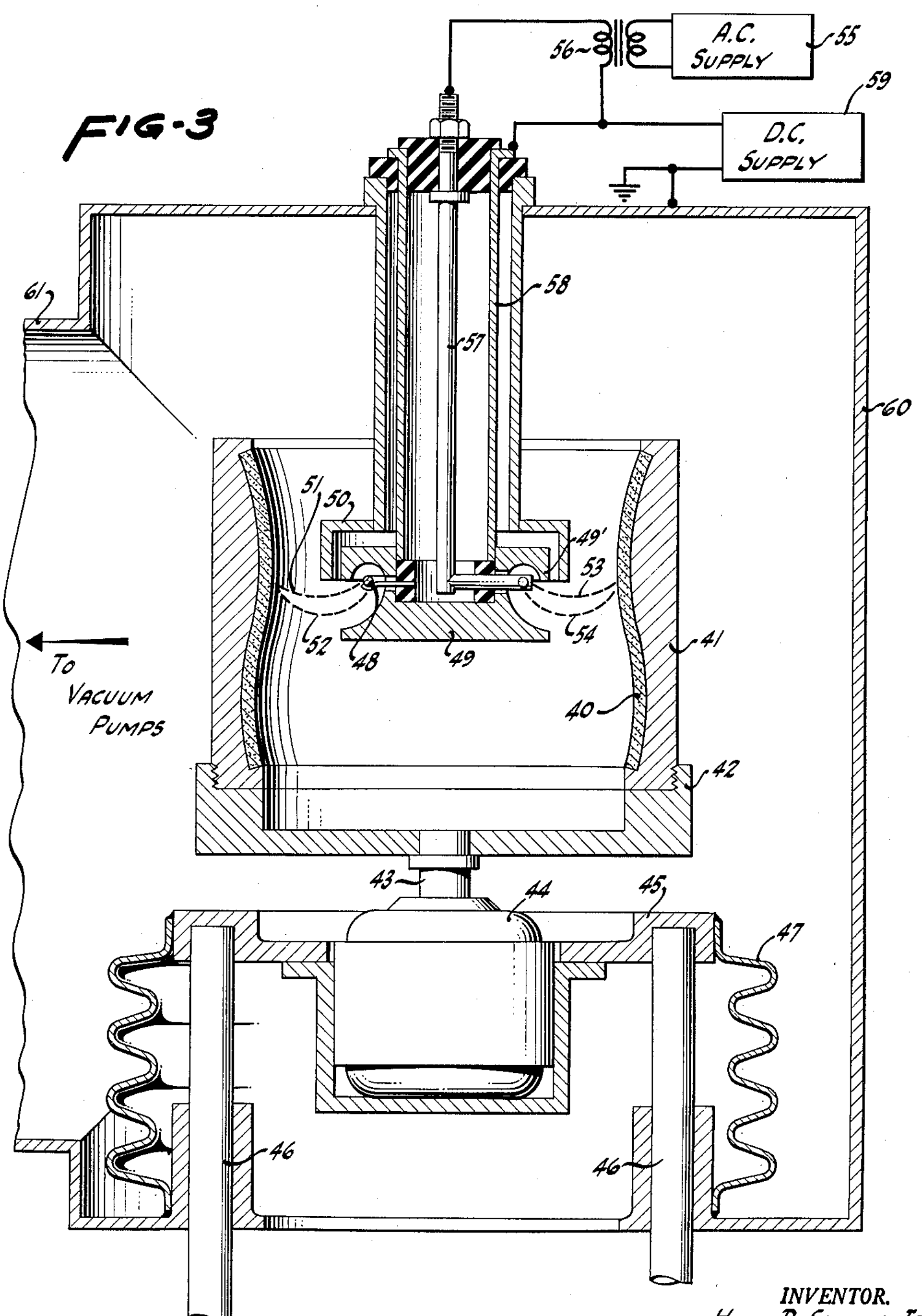
FIG-3



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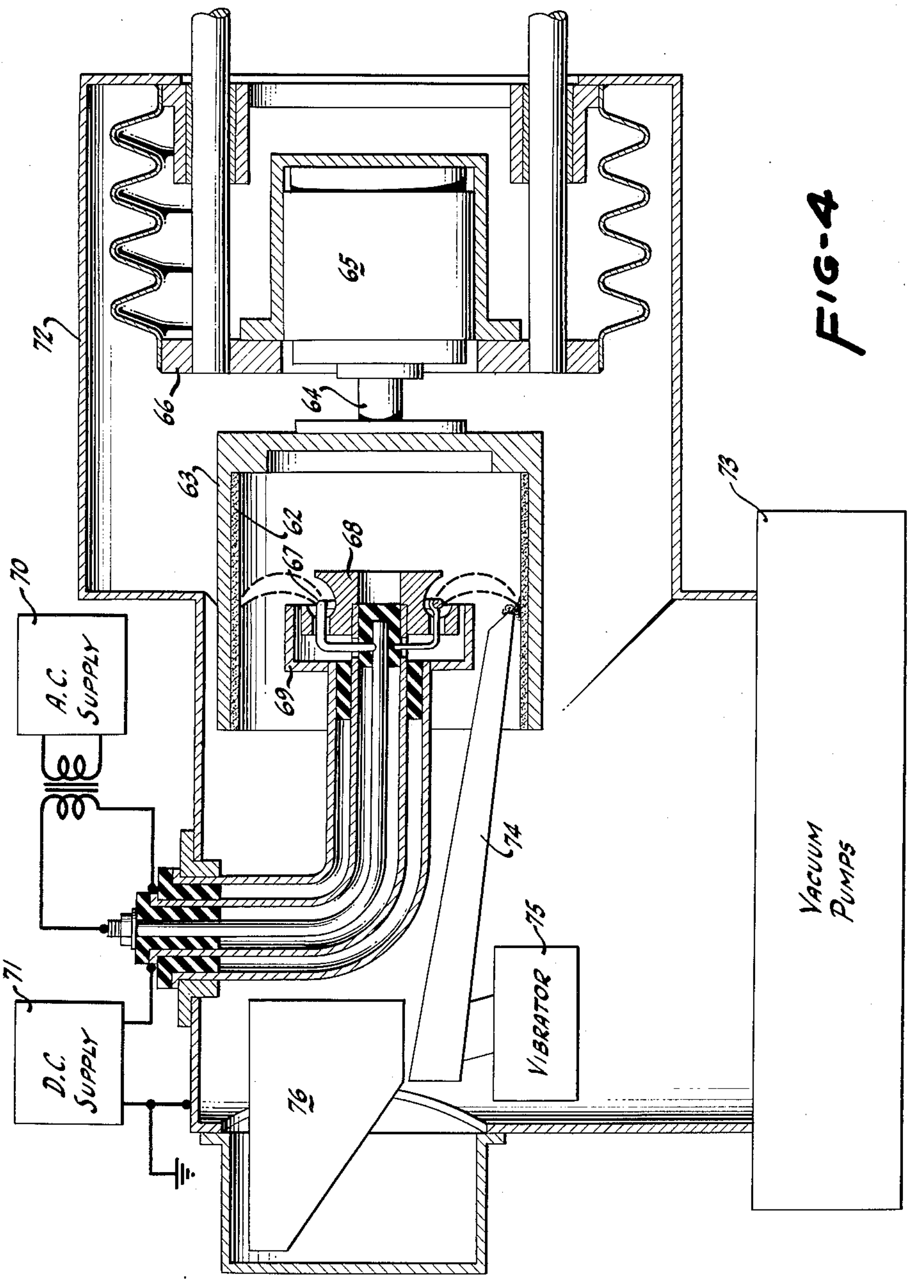

FIG-4

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APPARATUS FOR CENTRIFUGAL CASTING

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8 Claims. (Cl. 22—65)

This invention relates to the casting of articles having rotational symmetry about a central axis, such as cylinders, nozzles, and other shapes of substantially circular section, by forming a shell of compacted particulate or other solid material that is to be melted and cast and melting adjacent rings of this shell successively while rotating the shell about its central axis. The invention is particularly useful in casting relatively thin sections of material such as tungsten that tend to be brittle and to develop micro-cracks when cast in more massive form, but in its broader aspects the invention is not limited to the processing of any particular material.

In preferred practice, the invention is carried out by forming a hollow shell of the solid material which is to be melted and cast—e.g. by packing particulate material on the inner surface of a hollow mold, or by coiling wire inside a hollow mold. While rotating this shell about its central axis, a portion of the inside surface of the shell is bombarded electronically to heat and melt a narrow ring of the material, the greater portion of the shell being kept below its melting temperature by heat conduction to the mold and other heat losses. The ring of melted material is easily held in place by centrifugal force produced by rotation of the mold and shell. The melting zone is progressively moved in the direction of the axis of rotation, so that adjacent rings of the material melt and resolidify in succession. Thus the whole shell can be cast into an integral body; and, if desired, additional material can be placed inside the shell, melted, and cast to build up the thickness of the shell in progressive layers to any extent desired.

The foregoing and other aspects of the invention may be understood better from the following illustrative description and the accompanying drawings.

FIG. 1 of the drawings is a somewhat schematic, vertical section, showing one form of casting apparatus according to this invention.

FIG. 2 is a section taken along the line 2—2 of FIG. 1.

FIG. 3 is a somewhat schematic, vertical section of another embodiment.

FIG. 4 is a somewhat schematic, vertical section of another embodiment.

FIG. 5 is a fragmentary vertical section of still another embodiment.

Referring to FIGS. 1 and 2, the material to be melted and cast has been formed into a hollow shell 1 having rotational symmetry about a vertical central axis. In this instance the initial material is represented as being in particulate form—e.g., it may be tungsten powder. The shell 1 is formed and supported by packing it into a recess provided in the inner surface of a cylindrical mold 2, which may be of any appropriate material, preferably one having good heat conductivity, e.g., copper. Although shell 1 is shown as a cylinder, it is evident that it may be formed in a variety of shapes by using molds of different configurations. The mold may be cooled, if necessary, by surrounding it with a water jacket 3 through which liquid coolant, e.g., water, may be circulated continuously as hereinafter described.

A rotary shaft 4 is mounted in a suitable bearing 5. Attached to the upper end of shaft 4 is a chuck 6 for holding the mold 2 and associated parts in coaxial relation to shaft 4, so that the mold and shell 1 can be rotated about the vertical central axis of the shell by turning shaft 4. A motor 7 is connected to shaft 4 by any appropriate mechanical connecting means, represented by broken line 8, for rotating shell 1 continuously at a sufficient speed that centrifugal force will hold melted material in place upon the inner surface of the shell. Fluid passages 9 and 10, extending through chuck 6 and shaft 4 to annular recesses 11 and 12, provide means for the circulation of coolant through the water jacket from pipes 13 and 14 connected to conventional facilities for circulating cooling water.

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An annular portion of the inside surface of shell 1 is electronically bombarded, heated, and melted by a wheel-shaped electron beam, represented in the drawing by broken lines 15, 16, 17, and 18, generated by an electron gun comprising an annular thermionic cathode 19 and a focusing electrode, which in this particular embodiment comprises two parallel, circular plates 20 and 21. The electron gun is substantially symmetrical about the central axis of shell 1 and is supported by a vertical metal tube 22 extending downward into and coaxial with the hollow shell 1. The shell 1 being continuously rotated while the gun is non-rotating, a ring of material around the inside surface of shell 1 is uniformly heated and melted irrespective of any chance irregularities in the electron-beam pattern.

Focusing plates 20 and 21 are attached directly to metal tube 22, and the lower end of tube 22 forms part of the focusing-electrode structure. Cathode 19 is a substantially circular, horizontal loop of tungsten wire fastened at its ends to metal bars 23 and 24 and supported at several points around its circumference by a plurality of radial pins 25 projecting from insulating ring 26. Bar 24 is connected to tube 22 so that the metal supporting tube acts as one input lead to the filament. Also by this means, the focusing electrode is maintained essentially at cathode potential.

Bar 23 provides the second cathode lead, whereby current can be supplied through the cathode filament 19 for heating it to thermionic-emission temperature. For this purpose, alternating current is supplied through the cathode filament from A.C. supply 27 through transformer 28 and leads 29 and 30. The cathode and focusing electrode are maintained at a potential of several thousand volts negative relative to shell 1 by the connection of lead 29 to the negative terminal of a D.C. supply 31 having its positive terminal connected to shell 1 through the preferably grounded principal parts of the apparatus.

Tube 22, being at high negative potential, is supported in electrically insulated relation to the main body of the apparatus by means of insulator 32, tube 33, and support plate 34. Rods 35 and motor 36 are provided for moving plate 34 up and down at will, thereby moving the electron gun in the direction of the central axis of shell 1 relative to the rotating shell and associated structure. Thus, the location of the heated and melted ring can be moved up and down over the entire surface of shell 1, at will.

The rotating shell and mold and the electron gun are enclosed within a vacuum tank 37 which is continuously evacuated by connection to high-capacity vacuum pumps (not shown) through a large-area duct 38. Bellows 39 represents any appropriate vacuum seal to permit movement of the electron gun from outside the tank without loss of vacuum.

The apparatus is operated by rotating shell 1 about its vertical central axis, as hereinbefore stated, and causing the electron gun to bombard the inside surface of shell 1 and thereby melt a ring of material around said inside surface. The molten material is held in place by centrifugal force, and the greater portion of shell 1 is kept well below its melting temperature by heat conduction to mold 2 and other heat losses. By moving the electron gun up and down, the area of melting is progressively moved in the direction of the axis of rotation, whereby adjacent rings of the material of shell 1 are melted and resolidify successively.

After the melting zone has been moved over the entire height of the shell 1, the electron gun can be turned off and the material of shell 1 will have been cast into an integral cylinder. If greater thickness is desired, additional particulate material may be packed inside the cast cylinder and the process repeated as often as desired to build up the thickness of the cylinder layer by layer. At the conclusion of the casting process, the mold may be cut or etched away, or may be left in place as a backing for the casting.

A somewhat different form of the apparatus is illustrated in FIG. 3. Shell 40 of compressed particulate material has, in this case, been formed with a diameter that varies from top to bottom, this being the shape required for the finished part in a particular instance. The mold 41 has been formed with a corresponding shape. Water cooling of the mold has not been provided, it being assumed that the heat capacity of the mold, the allowable temperature rise, radiation heat losses, and the like, are such that water cooling is unnecessary in this particular instance. The chuck 42 holds the shell 40 and mold 41 in coaxial relation to shaft 43 rotated by motor 44. Movement of the electron gun relative to the shell 40 is achieved in this instance by moving the shell, mold, chuck, and motor up and down, the motor being mounted on a moveable support member 45 connected through rods 46 to any appropriate mechanism for moving it up and down at will. Bellows 47 represents any appropriate type of vacuum seal.

The electron gun comprises an annular thermionic cathode 48, a focusing electrode 49, and an accelerating electrode 50. In this case the focusing electrode has an annular lip 49′ extending downward outside of cathode 48 and substantially coplanar therewith, whereas accelerating electrode 50 is coaxial with and outside of lip 49′. The accelerating electrode is maintained at ground or anode potential and, being relatively close to the cathode, provides maximum acceleration of the electrons in the initial portion of their outward travel and increases the current that can be drawn from the cathode. The electric fields are highly curved in the vicinity of the gun by the electrode configuration shown, so that there is no appreciable electron bombardment of the accelerating electrode 50. The electrons are focussed into a wheel-shaped beam, represented by the broken lines 51, 52, 53, and 54.

An additional and important advantage of this gun configuration is that the cathode is to a very considerable extent shielded by lip 49′ from material evolved at the melting surface of shell 40. This protection of the cathode substantially extends the life of the electron gun. Cathode 48 is a circular filament heated to thermionic temperature by the passage of alternating current provided by A.C. supply 55 through transformer 56, rod 57 and sleeve 58. The cathode and focusing electrode are maintained at several thousand volts negative potential by connection of sleeve 58 to the negative terminal of D.C. supply 59. Accelerating electrode 50, shell 40, and mold 41 are maintained at ground potential through connection to the grounded principal parts of the apparatus. The rotating shell and mold and the electron gun are enclosed in a vacuum tank 60 which is continuously evacuated to a high vacuum by connection to vacuum pumps (not shown) through duct 61.

FIG. 4 illustrates a modification in which the axis of rotation is horizontal rather than vertical. Shell 62 of material which is to be melted and cast is supported within a hollow cylindrical mold 63 attached to a shaft 64 which is continuously rotated by a motor 65. The motor is mounted upon a horizontally movable support plate 66, whereby the stationary electron gun can be moved back and forth along the axis of rotation relative to the rotating shell 62. The electron gun comprises an annular thermionic cathode 67, focusing electrode 68, and accelerating electrode 69, all coaxial with the rotating shell 62. The gun operates in a manner similar to that shown in FIG. 3 and hereinbefore described, operating electrical power being provided by A.C. supply 70 and D.C. supply 71. The rotating shell and mold and the electron gun are enclosed within a vacuum tank 72 which is continuously evacuated by connection to vacuum pumps 73.

The embodiment shown in FIG. 4 incorporates an additional feature: means for continuously supplying additional material to the interior of shell 62 for building up the thickness of the casting. The additional material is supplied in particulate form through a feed chute 74 having its discharge end (on the right in the drawing) just above the bottom of the hollow interior of shell 62 and preferably adjacent to the ring of material melted by bombardment from the electron gun. A vibrator 75, or other conventional feed means, is employed to continually move particulate material from supply hopper 76 through chute 74 to its discharge end. Material falling from the discharge end of the feed chute falls onto the rapidly rotating inside surface of shell 62 and is held in place by centrifugal force until it is melted by the electron beam and finally resolidifies as an integral part of the casting.

FIG. 5 is a fragmentary view showing another modification. The hollow cylindrical mold 77 is rapidly rotated by attaching to the rotating shaft 78. The initial shell 79 is formed by coiling wire of the material to be melted and cast inside the hollow cylindrical mold 77. The electron gun 80 provides electron bombardment heating to melt a ring of the material in the shell as hereinbefore described. Additional material is supplied as desired by feeding in another wire 81 through the guide tube 82, which guides the wire into the interior of the hollow shell. The end of wire 81 is guided into the electron beam adjacent to the ring of melted material which the heat generated by the beam forms inside of shell 79. Thus the end of wire 81 is melted away and the so-melted material adds itself to the material inside the mold, whereby the thickness of the casting can be built up to any desired extent.

In its broader aspects, the invention is not limited tc specific examples illustrated and described. Numerous changes and modifications can be made without departing from the inventive principles herein disclosed.

What is claimed is:

1. Casting apparatus comprising rotary supporting means for holding a hollow shell of material to be melted and cast, means for continuously rotating said supporting means and shell about a central axis through the hollow shell, a non-rotating electron gun arranged to extend axially into said hollow shell and to bombard electronically the inner surface of the rotating shell for heating and melting a ring of said material, said electron gun comprising a substantially circular thermionic cathode coaxial with the rotational axis of the hollow shield and an annular focusing electrode shaped and arranged to focus electrons from the cathode into a wheel-shaped beam of outwardly-moving electrons directed onto a narrow circular area extending around the inside surface of the shell, means for moving said gun along said axis relative to said rotating supporting means and shell, a vacuum tank enclosing said supporting means and shell and electron gun, and means for continuously evacuating said tank.

2. Casting apparatus as in claim 1, said means for holding a hollow shell comprising a rotary shaft, a chuck attached to said shaft, and a substantially cylindrical, hollow mold held at one end by said chuck in coaxial relation to said shaft, said mold having a recessed inner surface for receiving and holding the hollow shell of material to be melted and cast.

3. Casting apparatus as in claim 1, said focussing electrode comprising a lip extending around the outside of said cathode substantially coplanar therewith, whereby the cathode is shielded from matter evolved from the melting surface.

4. Casting apparatus as in claim 1, additionally comprising feed means for supplying additional material onto the inner surface of said shell while melting is proceeding.

5. Casting apparatus as in claim 2, additionally comprising a cooling jacket around said mold, and means for continuously circulating liquid coolant through said cooling jacket.

6. Casting apparatus as in claim 3, said electron gun additionally comprising an annular accelerating electrode extending coaxially around and spaced outside of said lip.

7. Casting apparatus as in claim 4, the central axis of the hollow shell being substantially horizontal and said feed means comprising a chute extending into the hollow shell just above the bottom of its hollow interior, said chute having a discharge end adjacent to the ring of material melted by electron bombardment, and means for moving particulate material through said chute to said discharge end.

8. Casting apparatus as in claim 4, said feed means comprising means for feeding into said hollow shell a wire of the material to be melted and cast, and means for guiding the end of said wire to the region of said inner surface that is bombarded by said electron gun.

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