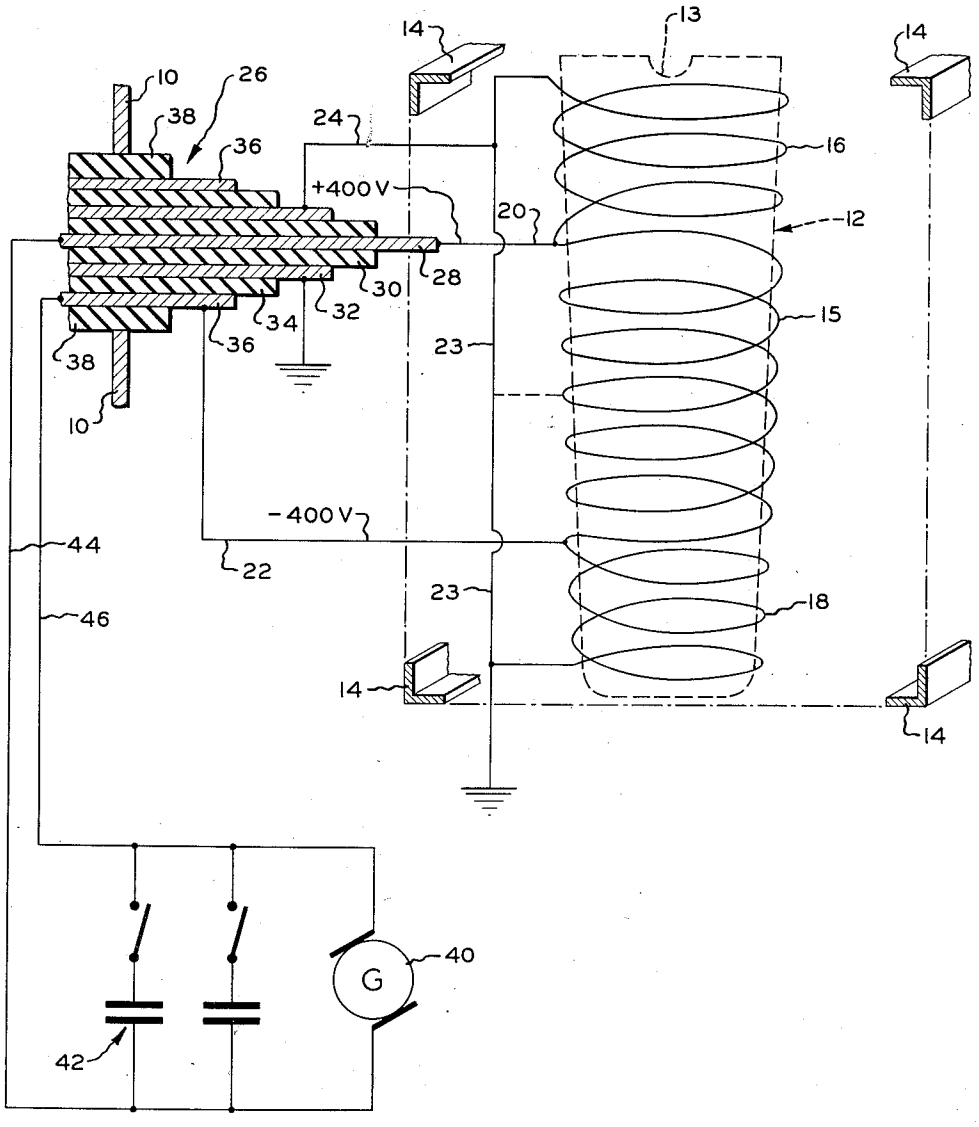
Aug. 20, 1957 M. P. HNILICKA, JR 2,803,689

ELECTRIC INDUCTION FURNACE

Filed April 2, 1956



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United States Patent Office 2,803,689 Patented Aug. 20, 1957

2,803,689

ELECTRIC INDUCTION FURNACE

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Application April 2, 1956, Serial No. 575,663

3 Claims. (Cl. 13—27)

This invention relates to the production of metals in large batches and more particularly to a novel vacuum furnace capable of producing large heats and ingots.

A principal object of the present invention is to provide a vacuum furnace of the type employing an induction coil for rapidly heating a large metal charge to its melting point, the furnace being safe to operate at high power levels requiring a relatively high voltage to be employed in the induction coil.

Still another object of the invention is to provide a large capacity induction vacuum furnace which retains a consistently high efficiency and uniformity of power coupling to the charge during the whole melting cycle, even during the initial melting period when the crucible may not be quite full.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing which is a diagrammatic, fragmentary, schematic view of a preferred embodiment of the invention.

Vacuum melting of small charges of metals contained in crucibles enclosed in evacuated furnace shells by application of induction heating has become a common and quite successful method for the production of small, high-quality melts and ingots. The use of induction heating for the operation of larger vacuum furnaces requiring higher coil voltage for increased power input into the charge has been seriously hindered, particularly at high vacuum (in the micron range), by frequent occurrence of destructive arcing and burnout damage resulting from ionization and glow discharge between the shell or structural metallic parts of the furnace crucible and high potential sections of the coil or power leads.

The necessity of intensive water cooling of the coil conductors and leads has greatly enhanced the acute danger, because a water leak produced by burnout rupture often produces, on contact with hot refractory and/or metal, large amounts of steam and/or hydrogen within the furnace shell resulting in damage by excessive internal pressure or destruction of the furnace by detonation of explosive hydrogen mixture, ignited by molten metal, as experienced on several installations.

In view of the above failures of efforts to use higher voltages, it has become a general practice to avoid, rather than overcome, the problems of ionization glow discharge and arcing by using relatively low voltages not exceeding 300–400 volts for the feed of the induction coil.

The accommodation of increased power at the above voltage limitation has necessitated the use of very high currents and heavy conductors for the coil with only a few turns. Accordingly, the given power input required for a reasonable rate of melting of a larger charge has resulted in a substantial decrease of the over-all efficiency of the furnace operation by combined effects of increased I^2R losses, eddy current and skin losses in massive conductors, as well as decreased uniformity of power coupling between the charge and an induction coil comprising only a few turns of parallel tubing of very heavy cross section.

The theoretical limit for the maximum charge is set by the inductance of a single turn coil which is capable of (*a*) encompassing the molten charge and (*b*) not exceeding the above voltage limitation at the required high current. In reality a single turn coil is not practicable. Therefore, in the past, the maximum size of the melt which could be safely produced in a vacuum did not exceed half a ton. Additionally, the initial cost of larger furnaces is further increased by the need for large step-down external transformers or an excessive number of capacitors to produce high capacitive currents at low voltages to tune the coil.

In the present invention, the difficulties in the prior art have been overcome by the physical superimposition of two induction coils connected in parallel for the metal-holding crucible. One of these coils is positioned adjacent the middle of the crucible and the other coil is split in two, approximately half thereof adjacent the top of the crucible and the other half thereof positioned adjacent the bottom of the crucible. The two half coils are attached to the center coil adjacent their inner ends and are reverse wound with respect to the center coil so as to produce an electromagnetic field which is in phase with the electromagnetic field produced by the center coil. These two extremities of the half coils are electrically connected by a jumper which is preferably grounded so that the half coils are also grounded at their outer ends. Consequently, there is no potential gradient across the narrow gap between the outer ends of the half coils and the crucible frame and/or the hot refractory near the pouring lip. The A. C. potential increases linearly with turns of the coil from zero at the half coil extremities toward a maximum at the connection to the power leads adjacent the center coil. Since these leads at the junction points of the center coil and top and bottom half coils (which are at the highest potential above the crucible frame) are located approximately one-quarter of the total coil length from each end, the high potential section of the coil is well spaced from the top or bottom of the crucible. This means that the potential gradient (volts/inch) existing between portions of the coil and the crucible support can be conveniently maintained below the ionization threshold by this construction. Across the center coil and both sections of half coils there is applied the full generator voltage of, for example, 800 volts. However, since, in the preferred embodiment of the invention, the jumper of the outer coil is grounded, it means that the coil is operating with one end potential, in reference to the crucible, which is instantaneously at no more than 400 volts positive. Simultaneously, the other end is at 400 volts negative and vice versa during the next half cycle, so that no portion of either coil is ever at a potential of more than one-half of the generator voltage (400 volts) above ground. If desired, the center of the center coil can also be grounded, preferably by means of a small resistor.

This arrangement of the induction coil, allowing use of a higher generator voltage combined with reduction of potential gradients below ionization, will permit safe operation of a coil at power levels substantially exceeding the above discussed limits of a single turn coil. Economically, it will reduce the cost of busbar connectors and decrease the size of the capacitor bank required for tuning or it can eliminate the need for a stepdown trans-

former. This arrangement of the coil also makes practical rapid melting of large charges and the production of ingots of several tons and contributes an important means for increased capacity of vacuum melting furnaces.

Since the applied generator voltage is double the actual maximum coil potential, the generator current for required melting power input is reduced by a factor of two, while the current through each coil conductor is reduced to one-quarter of that which would be otherwise needed. Consequently the I^2R losses and eddy current losses in leads and coil conductors are reduced and the efficiency of the coil assembly is greatly improved. Additionally, the construction of the coil with conductors reduced to 25 percent of the original areas is considerably easier.

From the standpoint of ease of construction and simplicity of installation, it is preferred that power be fed to the double coil by means of a coaxial conducting means comprising three conductors. The innermost conductor of the three is preferably connected to one end of the center coil, the outermost is connected to the other end of the center coil, and the intermediate conductor is preferably grounded, being also connected to the outer ends of the two half coils.

Referring now to the drawing, there is illustrated a diagrammatic, fragmentary view of the invention as applied to a vacuum furnace of the type generally illustrated in U. S. Patent 2,625,719 to Moore. For simplicity of illustration, only the induction coil, a portion of the coaxial conductor, the power supply and a small section of the vacuum furnace are shown in this drawing. The fragment of the vacuum-tight furnace wall is indicated at **10**, while the general location of the crucible is shown in dotted lines at **12**, with pouring lip at **13** and a portion of the grounded metallic crucible support frame at **14**, this being obviously a schematic illustration. The center coil is illustrated at **15** and the two half coils are shown respectively at **16** and **18**. Power leads **20** and **22** are connected to the two ends of the inner coil **15** and to the high-voltage ends of the coils **16** and **18** respectively. The extremities of these half coils are connected by a jumper **23** which is preferably grounded. Conductor **24** is also shown as being connected to the grounded intermediate conductor **32** of the coax assembly generally indicated at **26**. The coax includes an inner conductor **28**, an adjacent layer of insulation **30**, the intermediate conductor **32** (which is grounded), another layer of insulation **34**, and an outer conductor **36**. This whole assembly is carried in an insulated bushing schematically shown at **38** as extending through the wall of vacuum-tight housing **10**. Power leads **44** and **46** extend from the coax to a suitable generator **40** and condenser bank **42**.

In one preferred form of the invention, the generator operates at a frequency of 960 cycles per second. The coils are formed of copper tubing which is water cooled by suitable water connections thereto. One convenient method of introducing the water into the furnace chamber is to provide water passages (not shown) in the coax assembly **26**. The above-described arrangement provides for uniform distribution of water flow in both partial coils.

The present invention has the additional advantage that it also provides an improved coupling and power distribution when the crucible is only partially filled with molten metal. When the first charge is melted, the crucible is only half full. In the prior art arrangement with two coils in parallel, the presence of a molten metal slug in the field of the bottom coil and the absence of a metal slug in the field of the top coil result in a radical difference in the inductances of each coil. A very severe, if not altogether prohibitive, unbalance of currents in the coil fields results. In this invention the unbalance is eliminated by evenly distributing the effect of a half-full crucible between half of the center coil and the bottom half of the split coil. Thus each of the coils operating in parallel consists of the same number of turns with metal slug and without a slug and the unbalance is eliminated.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawing, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a vacuum furnace, the improvement which comprises two induction coils in parallel, one of said coils being positioned adjacent the middle of the crucible and the other coil being divided so that half thereof is adjacent the top of the crucible and half is adjacent the bottom of the crucible, the top and bottom ends of the top and bottom half coils respectively being grounded, the full generator potential being applied across the center coil.

2. In a vacuum furnace, the improvement which comprises two induction coils in parallel, one of said coils being positioned adjacent the middle of the crucible and the other coil being divided so that approximately half thereof is adjacent the top of the crucible and approximately half thereof is adjacent the bottom of the crucible, the two half coils being attached to the center coil adjacent their inner ends and being reverse wound to produce an electromagnetic field which is in phase with the electromagnetic field produced by the center coil, the two half coils being grounded adjacent their outer ends.

3. The furnace of claim 2 wherein the coils are energized by means of alternating current through a coaxial conducting means having three conductors, the inermost conductor being connected to one end of the center coil, the outermost conductor being connected to the other end of the center coil and the intermediate conductor being grounded.

No references cited.