Multipurpose Vacuum Induction Processing System

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Abstract. Multipurpose vacuum processing systems are cost effective; occupy less space, multiple functional under one roof and user friendly. A multipurpose vacuum induction system was designed, fabricated and installed in a record time of 6 months time at NFTDC Hyderabad. It was designed to function as a) vacuum induction melting/refining of oxygen free electronic copper/pure metals, b) vacuum induction melting furnace for ferrous materials c) vacuum induction melting for non ferrous materials d) large vacuum heat treatment chamber by resistance heating (by detachable coil and hot zone) e) bottom discharge vacuum induction melting system for non ferrous materials f) Induction heat treatment system and g) directional solidification/investment casting. It contains provision for future capacity addition. The attachments require to manufacture multiple shaped castings and continuous rod casting can be added whenever need arises. Present capacity is decided on the requirement for 10 years of development path; presently it has 1.2 ton liquid copper handling capacity. It is equipped with provision for capacity addition up to 2 ton liquid copper handling capacity in future. Provision is made to carry out the capacity addition in easy steps quickly. For easy operational maintenance and troubleshooting, design was made in easily detachable sections. High vacuum system is also is detachable, independent and easily movable which is first of its kind in the country. Detailed design parameters, advantages and development history are presented in this paper.

1. Introduction Vacuum metallurgy:
Vacuum is misnomer relative term which is used to represent the meaning low pressure. Processing of selective materials (metals, alloys, intermetallic and refractory materials) like titanium in gaseous environment cause metallurgical problems or unwanted reactions. To avoid the reactions vacuum metallurgy was developed a century back. In addition, composition and partial pressures of the various components are carefully controlled in vacuum metallurgy. The pressure range in vacuum metallurgy is from sub-atmospheric to ultrahigh vacuum (less than 760 torr to 10⁻¹² torr). The processes in vacuum metallurgy involve liquid/solid, vapor/solid, and vapor/liquid/solid transitions [1, 2].

The basic reasons for vacuum processing are elimination of contamination from the processing environment, reduction of the level of impurities in the product, and deposition with a minimum of impurities. In the vacuum process, impurities, particularly oxygen, nitrogen, hydrogen, and carbon, are released from the molten metal and pumped out during melting. There are numerous and varied application areas for vacuum metallurgy including special areas of extractive metallurgy, melting processes (Vacuum induction melting), casting of shaped products, degassing of molten steel, heat treatment, surface treatment, vapor deposition, space processing, joining(vacuum brazing, diffusion boning etc) processes, and testing of metals and alloys in controlled environments [2, 3].
Vacuum Induction Melting (VIM) is one of the important requirements for scientific research particularity in nonferrous metals and alloys arena. Oxygen Free Electronic (OFE) copper, copper-chromium alloys, silver containing copper, titanium alloys and super alloys are main materials among them. For International Thermonuclear Experimental Reactors (ITER), copper and copper-chromium alloys play important role. All these alloys are made by VIM and further processing [4, 5].

Several suppliers around the world offer processing equipments for vacuum processing like VIM. In many occasions, special purpose machines are built to satisfy the needs. But all these equipments are for particular applications or two similar applications. For example, systems built for vacuum induction melting cannot be used for surface treatment/heat treatment; Systems built for joining (vacuum Brazing) cannot be used for melting. Single operation oriented techniques (systems) like this are well suited for higher production. Butt research and development, pilot production, urgent requirement of some processing etc cannot afford the dedicated equipments for few experiments. So, a common platform is needed for the same which can fulfill various the needs with minimum effort and cost. This is similar to the assembly line of car factory. In this context, a multipurpose vacuum system was planned and built with operating vacuum ranging from 10⁻⁶ torr to 10⁻² torr.

2. Design and Fabrication:

2.1. Main sections of the designed system are as below

Main sections of the vacuum induction system are listed below and shown in Figure. 1 A and B.

1. Vacuum systems
   i. Pumps
      a. Mechanical
      b. Booster
   ii. Pipe lines (detachable, provision for capacity addition)

2. Control pack (easy and user friendly, semi automatic with manual override)

3. Power pack

4. Induction Coil

5. Materials handling systems
   i. Hot charge (for melting operations)
   ii. Mould/crucible load/unload (material handling mechanism)
   iii. Others

6. Chamber

7. Futuristic Ports for expansion/modifications

8. Subsystems which can be built if necessary
   i. Resistance heating hot zone
   ii. Mould chamber various outputs of induction melting

Possible operations, applications and methods:

2.2. Vacuum Induction Melting mode and refining pure metals and directional solidification of materials:

This process is suitable for the production of high-purity metals within an oxygen-free atmosphere. Refining of high purity metal and few alloys (eutectic alloys), electrode re-melting, investment casting, casting of aircraft engine components are few processes which can be carried out in this mode. For example, OFE Copper melting is done by using graphite crucible in VIM mode. It is melting, refining (keeping the liquid copper in vacuum for few hours to eliminate impurities and volatile matters), moving it slowly away from hot zone in such a way that the equilibrium solidifications starts at one end & ends at other end thus pushing all impurities to that end).
2.3. Vacuum Induction Melting ferrous and non ferrous alloys
For many specialized materials, vacuum induction melting is indispensable, which must be melted under vacuum or in an inert gas atmosphere because of their reactivity with atmospheric oxygen. This limits the formation of non-metallic oxide inclusions. This process contains melting, holding, and casting by tilting the coil + assembly and pouring the melted liquid in moulds. Thus, it differs from the option 2.2; pouring in this option is done in a separate mould. When non ferrous materials are melted, a conducting crucible like graphite is used.

2.4. Vacuum heat treatment chamber for resistance heating:
Induction coil and its accessories (coil assembly) are designed in such a way that it can be disassembled and assembled in 2-3 hours easily. In addition the assembly is completely detachable package so the vacuum chamber is free from any fitments which occupy space. After removing the coil assembly, and installing resistance heat shield + hot zone set up, it can be used as resistance heating high vacuum furnace. This chamber and hot zone can handle huge size and weight (up to 4000 kg job size in one batch). Ports are designed to accommodate induction and resistance feed through. Making a separate furnace for such large job is uneconomical as the number of jobs in such system are very few and occasional.

2.5. Induction heating system
The system can be used as induction heating system of large components by providing a graphite susceptor (easily detachable) inside induction coil, which makes the hot zone for billet hating for forming (rolling, forging), homogenization annealing and induction hardening processes etc. Crucible of the induction coil is removed which makes way for susceptor fixing. Susceptor is conduction source for heating non ferrous materials in induction heating system that acts as uniform heat distribution source manly for non ferrous materials [6].

2.6. Continuous production/operation for melting copper and its alloys:
Continuous casting is possible by adding bifurcation valves and separating mould chamber and melt chamber with separate vacuum lines. The mould chamber can be opened to atmosphere by keeping melt chamber in vacuum, which enables to remove ingots in continuous production.

2.7. Provisions for future expansion:
Future expansions as following are possible with minimum effort and cost.

   a. Power pack capacity and coil (increasing the capacity to 2 tons liquid copper from 1 ton) is possible with existing chamber, vacuum system. Feed through, coil support assembly can accommodate the increase.
   b. Increasing the vacuum pumping system by adding additional diffusion pump/vapour booster pump + rotary pump. Vacuum ports are provided for the same. This can be useful for expanding the volume of chamber in horizontal direction, for which provision is available.
   c. Extension of the vacuum chamber (design is in such a way that one side is fully detachable port)
   d. Continuous casting arrangements can be fitted for horizontal continuous casting.

3. Conclusions:
1. A multipurpose vacuum processing system was designed and commissioned successfully.
2. It contains provision for vacuum induction melting, refining, investment casting, directional solidification and induction heat treatments.
3. It has provision for future expansion by easy additions.
4. It is possible for changing the system to resistance heating system by detaching induction coils and assemblies, installing resistance heating hot zone.
5. Pumps, vacuum pipe line and chamber are easily detachable. This helps for easy servicing.
It has provision for continuous casting of copper and its alloys by adding simple set up.

Fig. 1. Schematic view (A) and photograph (B) of multipurpose vacuum system
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