

RAUTOMEAD TECHNOLOGY FOR CONTINUOUS CASTING OF OXYGEN-FREE COPPER, COPPER-MAGNESIUM & OTHER COPPER CONDUCTOR ALLOYS

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BACKGROUND

Since the company's foundation in 1978, Rautomead Ltd of UK has specialised in continuous casting technology for non-ferrous metals. Over that period, close to 400 systems have been built and installed at customer sites in 47 countries around the world. Graphite furnace technology is a distinguishing feature of a majority of Rautomead designs.

Rautomead plants are being used world-wide in production of

- oxygen-free copper
- copper conductor alloys
- a wide range of non-conducting copper-based engineering alloys
- gold and silver alloys
- zinc and zinc alloys
- lead and lead alloys

Forms include wire rod, straight length bars, flats and hollow sections. According to material and section size, the casting process may be vertical upwards, vertical downwards or horizontal. Casting machines are used either as integrated melting, holding and casting units or are set up to be fed with pre-alloyed liquid metal. In general, integrated lines are preferred when processing conductor materials to avoid oxygen pick-up in metal transfer or loss of volatile minor elements. In all applications, the product is semi-finished and requires to be further processed before becoming a familiar end-product.

FOCUS OF THIS PAPER

As this ICDC seminar relates to production of copper rod as an electrical conductor, I propose to offer you an insight into advances Rautomead has made in the technology of continuous casting of oxygen-free copper and copper conductor alloys including copper magnesium, but to make only brief mention of applications of this technology in other non-conducting applications.

OXYGEN-FREE COPPER ROD

It was in 1993 that Rautomead introduced an upwards vertical casting machine to produce 8mm dia. oxygen-free copper rod (C103) directly from Grade A copper cathode feedstock (Cu-CATH-1) using a single electrically-heated graphite crucible furnace. The graphite crucible is large enough to accommodate two separate chambers linked by a bottom transfer port. This permits a whole cathode sheet to be fed into the melt chamber with the molten copper transferring through the base to the adjacent casting chamber. Rod withdrawal is vertically upwards through water-cooled graphite dies immersed in the liquid copper. Five to eight strands are produced side-by-side and formed into coils. High purity graphite pellet/flake is used to cover both chambers of the furnace to protect the surface of the molten copper from oxidation. Heating is by low voltage graphite resistance elements. The cast rod is warm to the touch and below oxidation temperature when emerging from the casting dies.

In simpler systems, cathode feed is by manually operated electric hoist. More recent automated systems include automatic cathode feed and individual cathode weighing. This was a novel process when first introduced in the senses that it produced

- high quality copper conductor rod
- on a small scale
- directly at 8mm diam.



Fig. 1 Rautomead RS 3000 Copper Rod Casting Machine

Many refinements have been introduced since the early days, but the core technology has remained unchanged. Given a good quality Grade A cathode feedstock, the process produces an outstandingly consistent good quality oxygen-free copper wire rod. While the specification of C103 calls for an oxygen content of <10ppm, the natural reducing characteristics of the Rautomead system result in an actual oxygen content of <3ppm, so that the product is in fact the superior electronic grade C110.

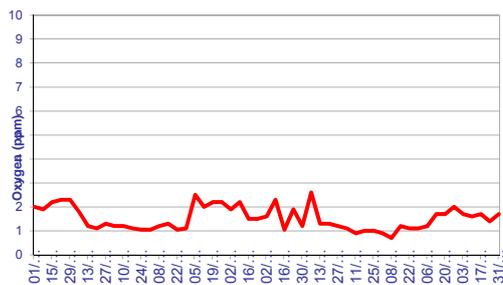


Fig. 2 Oxygen content measured over 12 months operation

Oxygen-free copper (Cu-OF) in its as cast state is softer and more malleable than electrolytic tough pitch copper (Cu-ETP). In drawing it must be work-hardened at the initial drawing stages. For example, when drawing from 8mm Cu-OF rod, the first two dies are set to give a cumulative area reduction of around 50%. This hardens the copper sufficiently to prevent subsequent wire breaks. For all subsequent drawing the Cu-OF wire behaves the same way as Cu-ETP copper with no further adjustments to the drawing process necessary.

It would be misleading to claim that Rautomead has never received a complaint about rod quality, but these have been exceedingly rare.

Graphite Crucible

At the heart of the machine is a crucible machined from extruded or vibration-moulded solid graphite. Sacrificial linings and inert gas are used to protect exposed surfaces from oxidation. The naturally reducing effect of the graphite material assists in ensuring the full de-oxidation of copper and avoids contact with and contamination of the melt by refractory particles.

An important feature of Rautomead furnace design is that the graphite crucible itself becomes part of the stored energy of the system, thus contributing significantly to thermal stability and enabling smaller furnaces to be used than in conventional channel induction furnace designs.



Fig. 3 Graphite Crucible

Graphite is elemental carbon. Mechanical properties of graphite are similar to those of ceramic materials, while thermal conductivity and electrical resistivity correspond to those of metals (see Table 1 below). It is this unique combination of refractory and metallic properties which makes graphite so well suited for use in electro-thermal processes at higher temperatures.

Key Parameters

bulk density of graphite crucibles	g/cm ³	1.83
open porosity	%	9
Young's modulus	kN/mm ²	10.8
flexural strength	N/mm ²	21.5
resistivity	Ωμm	7.7
thermal conductivity	Wm ⁻¹ K ⁻¹	165
coefficient of thermal expansion	10 ⁻⁶ K ⁻¹	2.7

Table 1

The change in electrical resistivity of carbon during the graphitization process is very marked. The material is transformed from being an insulator to a conductor. Thermal conductivity of graphite is at its maximum at about room temperature. Strength and Young's modulus increase with temperature and peak at ca. 2500 deg C., where values are 50-100% higher than at room temperature. Above 1400 deg C, the specific strength (strength/density) of graphite is greater than that of metals and most other refractory materials. Graphite used at higher temperatures is often exposed to sudden temperature changes or large temperature gradients, both introducing mechanical stresses.

Graphite Heating Elements

The good electrical conductivity of graphite enables this material also to be used as heating elements in a low voltage resistance furnace heating system. Secondary power is fed to water-cooled graphite busbars and to a chain of accurately rated heating elements which surround the crucible. The heat is fed to the metal in the crucible by radiation and convection and all at low voltage (typically 40 V). The furnace interior is protected from oxidation in an inert gas atmosphere. The arrangement is not only thermally efficient, but also very safe in operation.

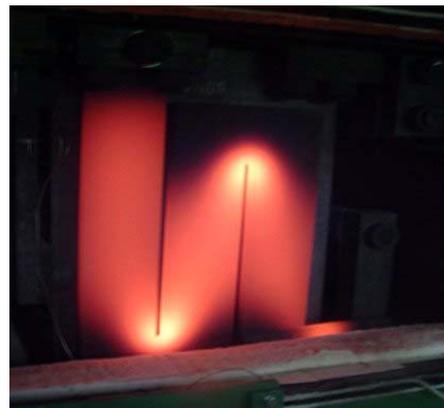


Fig. 4. Graphite Heating Elements

Still Metal Bath

Whereas induction heating tends to create an electromagnetic stirring effect in the molten metal, resistance heating in the Rautomead system delivers the energy through the walls of the graphite crucible and ensures a still metal bath. This avoids metal turbulence in proximity to the casting die and results in optimum casting conditions.

Oxygen Reduction

It is common to all casting systems of this type, whether of the graphite furnace type or the induction-heated type that it is necessary that oxygen must be reduced to extremely low levels (less than 10ppm) to conform to the relevant Standard and to achieve an adequate casting die life and thus an economically viable performance. Normal grade A cathode Cu-CATH-1) may be expected to include 60-80 ppm oxygen. In the Rautomead system oxygen is reduced in five steps:

- graphite pellet metal cover over melting chamber
- graphite sacrificial lining of upper part of melting chamber
- graphite walls of crucible
- graphite sacrificial lining of casting chamber
- graphite flake cover over casting chamber

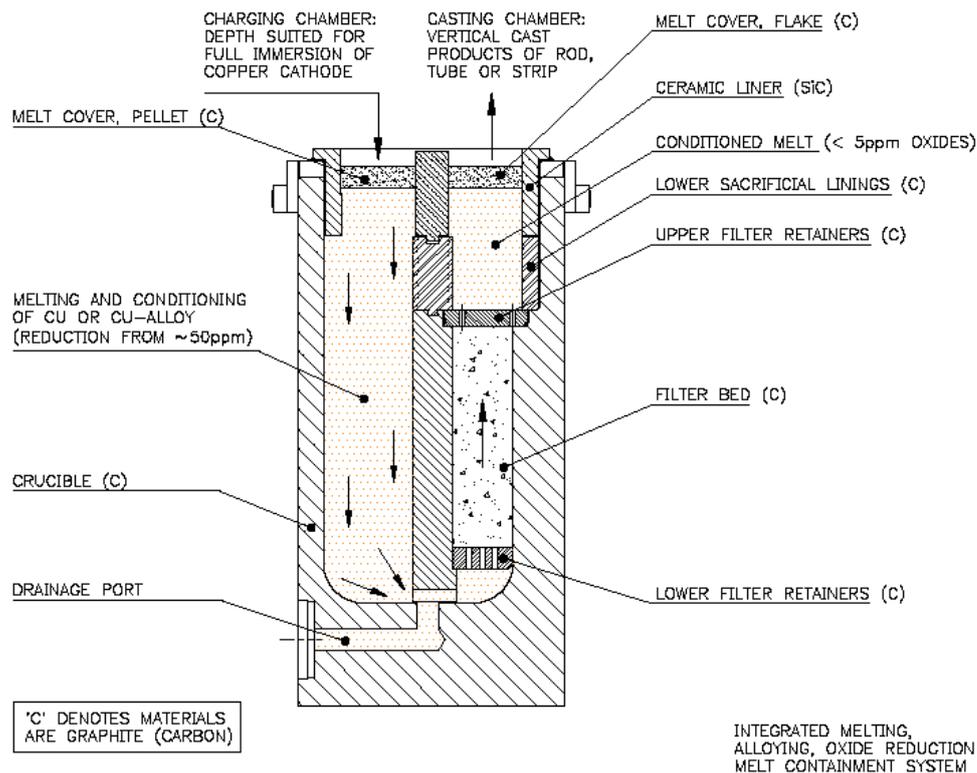


Fig. 5 Graphite Crucible Cutaway

Early tests (Fig 6 below) showed that a retention time of two hours was sufficient to reduce the oxygen content to less than 5ppm. Crucible holding capacity is typically 2,500 kg and output 500-700 kgs/hour, giving a retention time of 3.5 to 5 hours.

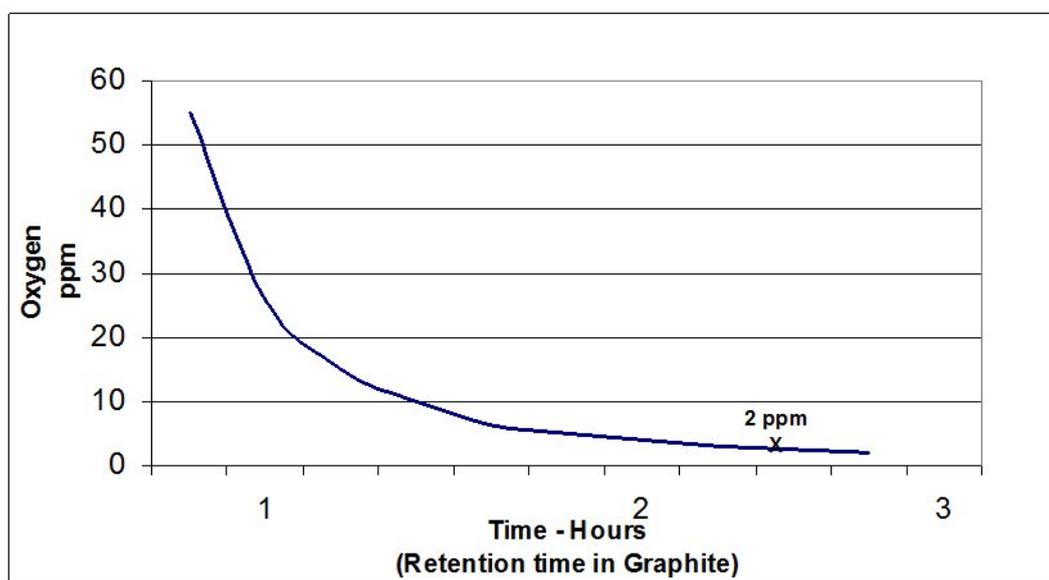


Fig. 6 Oxygen Reduction in Graphite Lined System

Casting Die Life

In production of 8mm dia. Cu-OF rod, graphite casting die inserts can be expected to produce around 12 tonnes of rod before the abrasive effect of the casting and solidification process causes the inside bore of the die to roughen. It is convenient to change the dies on all strands simultaneously coinciding with the completion of full coils. This takes approximately 60 minutes.

The Place in the Market for Small-scale Copper rod Manufacture

It is often asked what is the place for small-scale production of Cu-OF copper rod in a market environment where by far the majority of copper rod for the wire and cable industry is produced on large CCR plants producing electrolytic tough pitch copper (Cu-ETP) with its attendant advantages of scale.

In Cu-ETP production, oxygen is intentionally alloyed with the copper and is controlled to around 200-400ppm. The oxygen acts as a scavenger for dissolved hydrogen and sulphur and also reacts with most other impurities to form insoluble oxides at the grain boundaries. This prevents them from dissolving in the copper matrix adversely affecting conductivity and annealability. However, these hard particles are prone to cause wire breaks when drawn as a wire to fine and superfine sizes.

By contrast the Rautomead process typically has 3ppm or less oxygen. It is thus inherently more demanding in terms of the purity of the cathode feedstock, but the negligible presence of oxide particles greatly reduces the incidence of wire breaks in drawing to fine and superfine wire of 50 microns and less. Modern multiwire machines are designed with up to 56 strands and where one break interrupts the process. The benefit of reduced wire breaks becomes of significant importance in reducing overall cost of manufacture.

The majority of users of the Cu-OF rod process have purchased their machines not so much because they required a product which would be oxygen-free as because they wished to have a process which offered

- consistently high quality copper rod
- less wire breaks
- less operators in wire drawing operations
- output which matched their requirements
- investment which matched their means
- freedom to operate independently from the major mills
- ability to recycle in-house scrap arisings
- reduction in overall operating costs

Equally it is often asked why a wire and cable producer needs Cu-OF, when Cu-ETP is the standard product in the industry. Some customers have purchased their Rautomead machine with a specific requirement for Cu-OF. Those have tended to be specialist cable companies requiring properties in the copper rod of:

- greater ductility
- lower noise
- lower surface oxides
- avoidance of hydrogen embrittlement

Examples include:

- automotive wiring harnesses
- aerospace
- robotic arms
- ribbon cables

where the copper conductor of the cable is subjected to repeated flexing

- headphones in the civil and military spheres
- audio cables

where low noise is critical.

- feedstock for the continuous extrusion process where during extrusion the material will be heated to the point where it becomes plastic but does not become molten

where an absence of surface oxides on the rod is necessary for direct extrusion of busbars and commutator sections .

Each of these are niche markets where quality and special properties are key features and where annual output requirements of 5,000 to 10,000 tonnes are often appropriate.

Process Improvements

Over the years, significant steps have been taken to improve the process. These include:

- automatic cathode feed
- simultaneous production of rods of different diameters
- rods from 8mm up to 32mm diameter
- cathode weighing
- higher casting speeds and reduced number of strands
- touch screen controls
- SCADA data recording with remote monitoring

- larger coils - (now up to 5 tonnes)
- use of in-house scrap arisings
- reduced thermal stress
- improved refractories

COPPER CONDUCTOR ALLOYS

By a process of lateral thinking, technical innovation to meet a specific need in the market place often leads to parallel advances in other applications of a process. In the Rautomead case, we have found that our compact single furnace graphite crucible design has led to other market opportunities for production of dilute copper alloys.

Most of these are in conductor applications of copper with the alloying elements added to provide special properties including:

- greater strength
- reduced creep
- higher softening temperature
- lower materials cost

than would be offered by copper alone.

Examples include:

<i>Principal Applications</i> \ Alloy type	CuAg	CuSn	CuMg	CuCd	CuZr	CuCrZr	CuFe
<i>railway catenary wire</i>		▨	▨			▨	
<i>medical applications</i>					■		
<i>automotive signal wire</i>	▨		▨	▨	▨		▨
<i>commutator sections</i>	▨						
<i>switches</i>					▨		
<i>cable terminals & connectors</i>			▨				▨
<i>welding nozzles</i>					▨	▨	

Table 2

Copper-magnesium

When copper-cadmium was banned in Europe for toxicity reasons as an alloy for railway catenary systems, the industry was left with a choice of other materials for contact wire (table 3 below)

Material		resistivity	elong (min)*	tensile strength (min)*	max speed (kmph)
		10^{-08} Ohm.m	%	N/mm ²	
electrolytic copper	Cu-ETP	1.777	3	355	160
copper-silver alloy	Cu-Ag 0.1	1.777	3	360	250
copper-tin alloy	Cu-Sn 0.4	2.155	3	430	360
copper-magnesium alloy	Cu-Mg 0.5	2.778	5	490	400+
			* nom. cross section 100mm ²		

Source: European Standard EN 50149 of December 2001

Table 3

The choices to be made are matters for the railway authorities around the world, but as design train speeds have increased so the tension required in the contact wire has risen to ensure a safe margin is maintained between maximum train speed and the wave propagation speed to avoid catastrophic accident. This has favoured copper-magnesium for use in such catenary systems as a rapidly work-hardening alloy. All the major CuMg producers in Europe as well as multiple producers in China have adopted Rautomead technology.

The distinguishing feature of the Rautomead technology from that of almost all its competitors is the adoption of a resistance heated graphite furnace for melting, alloying and casting. The characteristics of this design have shown themselves to be uniquely well-suited to production of CuMg and other dilute copper alloys. This is not induction melting, neither coreless or channel type. No eddy currents flow through the copper alloy charge. No clogging of inductors with magnesium oxide. Rather, the metal is heated by radiation and convection through the walls of the graphite crucible, minimising turbulence and slag formation and facilitating close chemical composition control in alloy production.

Challenges in Dilute Alloy Production

1. Composition Control

Minor changes in alloy chemistry in dilute copper alloys often have marked effects on physical properties.

In the case of CuMg for example, the challenge is to maintain a precise and delicate balance between low electrical resistivity of copper and high tensile strength introduced by the addition of magnesium. A typical CuMg alloy for railways trolley wire (EN 50149:2001) is specified as CuMg0.5 with a magnesium tolerance of +/- 0.03%. The product is finished either as a single strand shaped contact wire or as a stranded cable for the messenger wire and the droppers.

Magnesium is a light and volatile element with a density of less than 20% of that of copper and prone to slag formation. Maintenance of such a tight chemical tolerance in continuous production is a serious challenge, but one where Rautomead totally enclosed furnace technology has shown itself to be a consistent and reliable choice.

2. Alloy Addition

A variety of techniques has been developed by Rautomead for alloy addition, according to the material to be produced. These include:

2.1 Manual Addition of Elemental Magnesium Wrapped in Copper Foil

In simpler systems, this technique has shown itself to be effective, though it does depend on regular human intervention and the reliability of the operator.

2.2 Automatic Grain Feed

This is used in production of copper-silver and copper-tin, where a PLC-programmed automatic grain feeder is positioned above the melting chamber of the crucible to deliver a measured weight of silver or tin grain through a graphite tube submerged in the melt. Cathodes are individually weighed and the PLC is used to calculate the precise grain addition to match production rate.



Fig. 7 Automatic Grain Feeder

2.3 Single Cored Wire Feed

A relatively recent introduction to continuous casting of dilute copper alloys has been a cored wire feed. This was developed initially to automate the addition of magnesium powder in production of CuMg alloys for catenary wires in high speed train systems. The cored wire comprises a copper sheath enclosing a core of magnesium powder. Typical OD of the cored wire is 13mm and the composition of the feed 50:50 copper and magnesium. Speed of the cored wire feed is electronically geared to production rate. The cored wire is plunged through the protective graphite or charcoal cover to melt and disperse in the melt side of the graphite crucible. Practical long term testing in an operating environment has shown a marked reduction in magnesium losses and improved accuracy of composition control compared with manual feeding.



Fig. 8 Cored Wire Feed

2.4 Twin Cored Wire Feed

The cored wire feed principle now been extended to more challenging alloy work including copper-chrome-zirconium, with typical compositions of 0.6% chrome and 0.05% zirconium, where two alloying elements are added as separate cored wires.

3. Closed Furnace Lid with Cored Wire Feed

In dilute copper alloy work prone to rapid oxidation, a closed furnace lid approach is now used with the surface of the molten metal protected in an inert gas atmosphere. In recent experimental work at our research facility in Dundee, a steady furnace pressure of over 70mm water gauge has been maintained. In this case the copper is fed as a rod and the alloying elements as cored wire enabling very close tolerance to be maintained in feed rates of all elements comprising the alloy and avoiding exposure of the melt to atmosphere. This is not vacuum melting, but a combination of techniques which enable the continuous casting process to achieve comparable results.

4. High Temperature Alloys

Whereas a furnace temperature of around 1350 deg C is normal in production of Cu-OF, Rautomead has now developed a furnace designed to operate at 1550 deg C using ceramic crucibles and casting die materials for iron-containing copper alloys providing high strength and low materials cost.

IN SUMMARY

The Rautomead oxygen-free copper rod casting process has been around for over twenty-five years. It differs radically from the CCR process, both in terms of the specification of the copper produced and in the scale of operation. It is a complementary but not a competing process. It differs also from almost all of the other oxygen-free casting technologies available in its use of graphite crucible furnaces which we consider to give the highest and most consistent quality of oxygen-free copper rod available.

On the domino principle, Rautomead technology has now moved on to become a widely accepted process for production of dilute copper conductor alloys including copper-magnesium, where accurate control of volatile minor elements is an essential ingredient of success.

A driving force within Rautomead is to advance the technology to meet the needs of the changing world. We work closely with client companies from around the world in developing new applications for the process and in evaluating new materials. To that end, the company is equipped with comprehensive R&D facilities including upwards vertical and horizontal casting test facilities, laboratory analytical facilities and most importantly a team of dedicated and experienced engineers and metallurgists. Close links are also maintained with the University of Dundee. Current work includes specialist applications of CuZr, CuCrZr and CuAg.

In the modern connected world in which we live, the thrust of much of this effort is for Rautomead to play an active role in providing technology which makes electrical conductors of all types and in many industries stronger, smaller, lighter and less expensive.



Fig. 9 Rautomead RS 3000/5-Cu-Mg Casting Machine

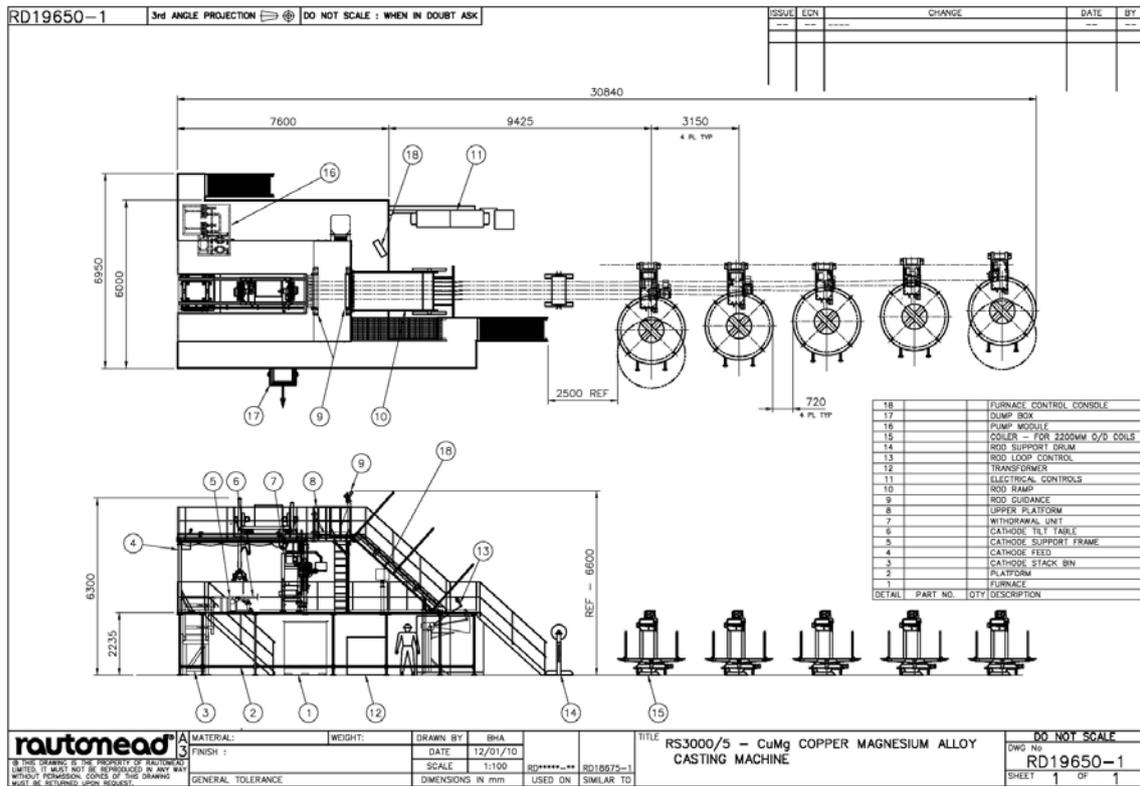


Fig. 10. Rautomead RS 3000/5-Cu-Mg Casting Machine Layout

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