Light Metals 2012 *Edited by: Carlos E. Suarez*
TMS (The Minerals, Metals & Materials Society), 2012

DEVELOPMENT OF A NEW GENERATION ELECTROMAGNETIC METAL MOVING SYSTEM

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Keywords: Electromagnetic, Stirring, Casting, Transferring

Abstract

Fives Solios have developed an innovative new generation electromagnetic metal moving system called ***GENIOS*** that can be incorporated within new installations or retrofitted to existing furnaces. It can be fitted simply and safely to a wide range of furnace types using a patented modular interface and mounting concept.

The prototype system is being trialed on a 70 tonne capacity static holding furnace at a large modern re - melting facility in Europe. In this particular case, the system is configured to stir, aid silicon dissolution and transfer to a dedicated continuous casting machine. The trials are in progress and expected to be completed during 2011.

This paper will give an overview of the development of the concept and technology. It will also include a brief review of the performance of the prototype and general operational experiences together with comparisons with traditional technology.

Introduction

Fives Solios have been working with various forms of metal moving systems as part of their furnace business for many years. Most of the commercially available systems have inherent disadvantages, either from a commercial, performance or practical viewpoint. In order to overcome these issues, it was decided to develop an in- house system starting from a clean sheet of paper, that could offer both commercial and operational benefits.

This new system (called ***GENIOS***) is an electromagnetic based system for moving molten aluminium. To maximize flexibility, the concept was designed to be capable of the following functions using a single inductor:

1. Stirring of molten metal within a furnace or chamber.
2. Transfer of molten metal to a crucible, holding furnace or casting machine.
3. Aid submergence and dissolution of alloying elements or scrap materials into a molten metal bath.

The prototype was tested under laboratory conditions during 2009. This was undertaken to prove the basic design concepts and define the electrical, magnetic and physical characteristics of the system. Following the successful conclusion of this work, a suitable production facility was then sourced in order to test the equipment in the field under typical production conditions.

In 2010, a joint agreement was reached with Vedani Carlo Metalli (VCM), a large technology focused European secondary producer, to trial the prototype on an existing 70 tonne capacity casting furnace at their plant in Parona, Italy. The system was installed during the early part of 2011 and continues to give valuable operational experience and data .

System Description

The overall system consists of several major elements, each with a particular function

Components required for basic stirring/circulation applications are:

1. Inductor - This device produces the actual electromagnetic field, so inducing movement within the molten metal.
2. Mounting Interface – This is the physical interface between the working face of the inductor and the molten metal. It consists of various refractory and metal components arranged in layers, all contained within a fabricated steel structure or port. The port also provides the mechanical mounting arrangement to locate and hold the inductor [1].
3. Water Cooling System – A self contained closed circuit water cooling system is used to provide an adequate supply of demineralised cooling water to the inductor. A suitable emergency backup supply is also provided.
4. Power Supply – These are the various electrical devices that manipulate the system incoming electrical supply in order to feed the inductor with the correct voltage, current and frequency it needs to perform its required function. These devices are mounted within an enclosed electrical cabinet.
5. Human Machine Interface – An HMI is used to allow the operator to control & monitor the operating functions of the system.

For casting and transferring operations, the following additional components are required:

1. Casting Channel –When in transfer/casting mode, a suitable channel is required to define and contain the metal flow. This takes the form of a retractable structure (usually called a "sled") onto which are mounted shaped refractory tiles that form the channel.
2. Casting Frame –This is the frame that supports the casting sled and contains the casting drive.
3. Casting Drive –This drive moves the casting sled so that the channel is submerged into the molten metal to a pre determined depth.

Figure 1 below shows the arrangement of the main components of the system.

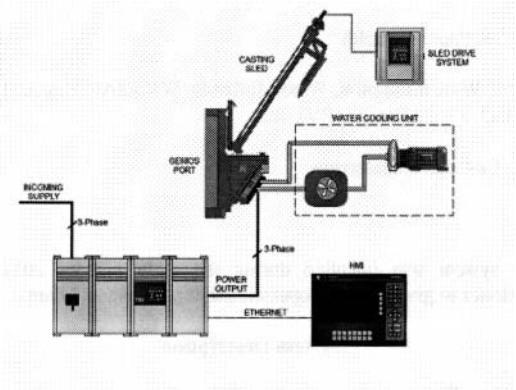


Figure 1. Arrangement of Major Components

Electrical Control System

The main elements of the electrical control system are:-

1. Power Panel (including Inverter)
2. Programmable Logic Controller (PLC) Panel
3. Human Machine Interface (HMI)Control Desk
4. Casting Channel Sled Drive
5. Casting Remote Input & Output (RIO) panel
6. Launder Remote Input & Output (RIO) panel

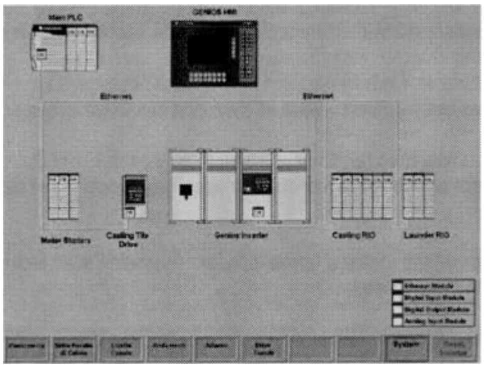
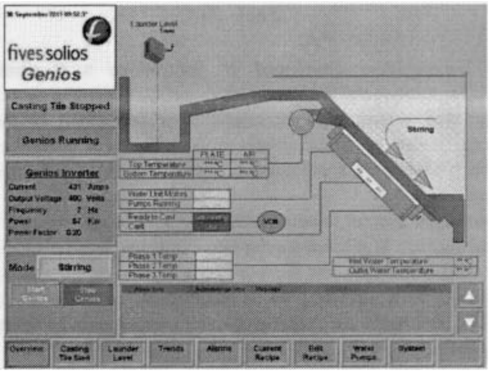


Figure 2. System Architecture

The power panel contains the variable frequency drive for the inductor. This drive is configured specifically for controlling non-motor applications.
Plant control is via a PLC system utilising Ethernet Input/Output. To view all plant data and alarms related to the Genios system, a dedicated HMI system is provided for at the control desk. The HMI communicates to the PLC system via an Ethernet connection. Remote access to the system from Solios Thermal premises is catered for by the use of a Virtual Private Network (VPN) link. This allows full access to all recorded data and facilitates the ability to make on line changes to the PLC, HMI and Inverter drives. The system consists of 2-modes of operation:

Stirring Mode

In stirring mode the Inverter frequency is set to the required value with its output voltage set to maximum voltage. A recipe within the HMI is configured that allows for a periodic cycle of stirring to be employed.

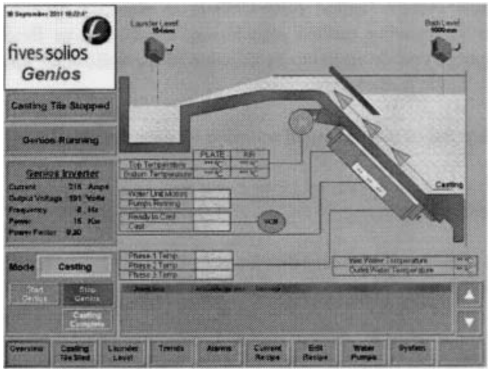


Genios Inverter
Current 431 Amps
Output Voltage 480 Volts
Frequency 7 Hz
Power 67 Kw
Power Factor 0.20
Mode Stirring

Figure 3. Typical HMI Graphic Display – Stir Mode

Casting Mode

In casting mode the Inverter frequency is set to the required value and it's voltage output controlled via Proportional Integral Derivative (PID) action depending upon the metal level in the launder. The metal level is measured via a laser sensor at the launder. The position of the casting sled is controlled by knowing the metal level in the furnace bath and the sled's relative position. Both metal level and sled position are measured by the use of separate lasers.



Genios Inverter
Current 218 Amps
Output Voltage 191 Volts
Frequency 8 Hz
Power 15 Kw
Power Factor 0.20
Mode Casting

Figure 4. Typical HMI Graphic Display – Cast Mode

Safety Considerations

Safety is always the prime consideration for any Industrial development. This is especially true in all processes dealing with molten metal.

There has always been a long held belief within the Industry that mains frequency (50/60Hz) stirring systems are inherently problematic because of the relatively small depth of magnetic field they produce. This results in a thinner refractory interface between molten metal and inductor and so an increased risk of leakage.
Although with careful design and installation a workable system could be found, Solios Thermal felt that a more robust approach was needed to satisfy these concerns. Two areas were addressed:

1. The operating frequency envelope of this system has been designed to be between 5 and 10Hz. This gives a significant advantage over mains frequency units with regard to field depth and allows more scope to design a good interface between inductor and molten metal.

2. A patented interface concept has been developed that utilizes composite ceramic components in conjunction with insulative layers and a final stainless steel closure plate. The closure plate is designed to minimize field loss. For additional security, the plate incorporates an air gap between the inductor working face to allow cooling air to be introduced via a small integrated fan.

It is worth noting that the new system is inherently failsafe during cast abort situations in as much as if the power is cut, the pumping action stops immediately.

Electro Magnetic Emissions

Electromagnetic radiation emitted from the inductor casing during operation is a very important subject regarding personnel safety and electromagnetic interference with local equipment. The 1998 ICNIRP (International Commission on Non – Ionising Radiation Protection) guidelines for limiting exposure to magnetic fields [2] was taken as the defining document for assessing risk.
The magnetic flux density emitted from the sides and rear of the inductor casing was measured at increasing distances under free field conditions. These revealed that over the normal operating frequency range, emission levels fall to below the recommended exposure limit at a distance of 1.2 metres from the inductor casing.
In practice, any emissions will be attenuated by the presence of local steelwork and other structures. Measurements taken on site showed actual maximum levels were well below the recommended exposure limit in the working areas around the port.

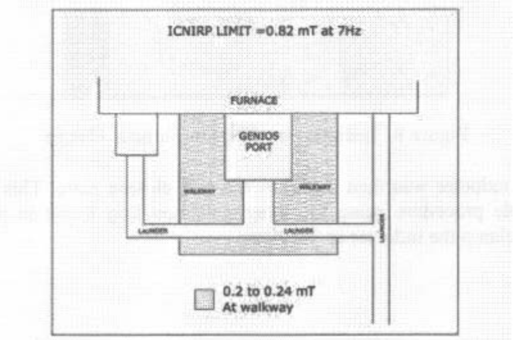


Figure 5. Typical Emission Measurements

Operating Philosophy

This is a very flexible system – the inductor is bi - directional and can produce a moving magnetic field of variable frequency and variable voltage in either direction. As the inductor is positioned on a vertically inclined plane with respect to the bath, a stirring action can be induced by directing the field down the plane. Reversing the direction of the field allows the possibility for molten metal to be drawn up the plane and effectively pumped from the furnace.

Stirring Mode

Stirring is accomplished with the magnetic field moving down the inclined face of the port, so directing metal from the surface of the bath and reintroducing it along the furnace floor. This action also induces horizontal flow components within the body of the bath itself and produces an effective overall stirring effect.
One advantage of this approach is that the surface of the metal remains relatively undisturbed with little tendency to produce dross.
The unobstructed access to the molten bath and the open geometry of the port interior lend themselves to unimpeded metal flow and minimal potential bridging / blockage issues. This arrangement also allows "dry hearth" operations for alloying applications.

Transferring / Casting Mode

Reversing the direction of the magnetic field will move molten metal up the port slope and out of the furnace. However, this can lead to fall back of metal back into the bath – so promoting "foaming " and dross build up at the base of the port. Also, the degree of control and resolution required to feed metal directly to a casting machine cannot be met. A defined channel is needed to confine the flow and to prevent metal falling back into the furnace before it reaches the top of the slope and so into the launder.

Conventional side mounted inductors used for pumping metal from furnaces normally utilise a solid plate positioned in front of the working face to form a channel in which the metal can flow up into the outlet launder.
Normally, this channel plate is made from some sort of refractory material and permanently fixed in position. This means that the inductor can only be used for pumping /casting and not for stirring the metal because the plate is always obstructing the working face.
Solios Thermal have developed part of the new technology to address the above issues [3]. This is a moving channel concept whereby the channel sled is driven into the molten metal so that it follows the reducing bath metal level as the cast proceeds. Only the casting channel nose needs to be submerged to define an adequate channel.
There are two ways of achieving this:

1. Continuously drive the channel sled with a proportional feedback loop from measuring the bath level. This would be the ideal way, but it could lead to problems with drive ratios and resolution because of the very slow change in bath level.

2. Step drive the channel sled into the bath in increments over the duration of the cast, so that the nose of the channel will always be submerged within a given range. This is the procedure adopted with the prototype installation.

Manipulating the channel in this way gives us certain advantages:

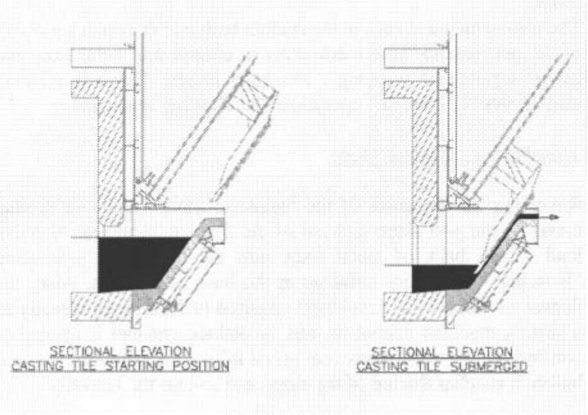
1. Only the nose of the channel needs to be made completely of a refractory material. The remaining sections of the channel can just be refractory faced. This means smaller refractory sections and easier maintenance.

2. The rear of the channel can be metallic, which offers strength and rigidity.

3. The casting channel face can be profiled to optimize the metal flow.

4. The whole channel and drive assembly can be arranged to retract completely out of the way when not in use to give good access and reduce the risk of damage during other furnace operating procedures.

Figure 6. Shows the casting channel in the retracted and submerged positions



Site Installation

Existing Trial Furnace

The trial furnace is a conventional static reverbatory casting furnace fired by natural gas regenerative burners. It is of 70 tonne nominal capacity and runs with a typical bath depth of 1000mm.
Charge is predominantly molten metal via a metal inlet port laundered from a number of supplementary melting furnaces. A small proportion of solid scrap / alloying elements are charged through the main door as required.
The furnace is used to feed a dedicated belt type continuous casting machine at a rate of between 12 and 20 tonnes /hour. The existing form of transfer is by means of a mechanical graphite pump with an air motor drive. To overcome the inherent lack of flow control associated with this type of pump, a weir system was employed to feed excess metal flow from the pump back to the furnace.

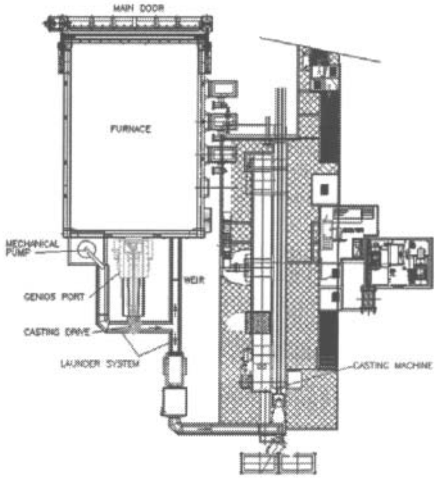


Figure 7. Plant Layout

Installation of the Port / Inductor Assembly

The system port was centrally mounted on the rear wall of the furnace. The refractory "window" and mounting flange for the port were installed by VCM according to Solios Thermal specifications during a normal scheduled shutdown period and necessitated only simple refractory and structural modifications to the furnace.
The port was retrofitted to the furnace as a complete modular unit with pre-dried refractory lining and all other interface components already fitted as shown in Figure 8.

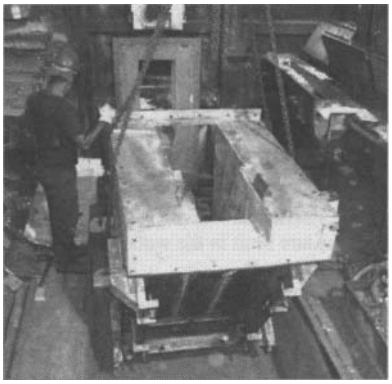


Figure 8. Installation of Port to Furnace Flange

The inductor was then mated to the port closure plate. This is a simple procedure using the integrated mounting frame to pivot and clamp the inductor in position.

Figure 9. Inductor Mounted to Port

The casting mechanism was mounted to the furnace structure above the port. The casting sled is shown partially inserted into the port in the photo below:

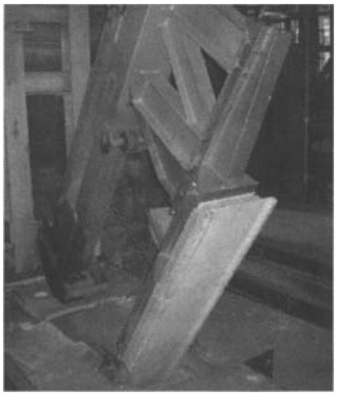


Figure 10. Casting Mechanism.

Operating Experience

System Design Parameters

The system operates within the specified electrical and process parameters predicted by the theoretical design.

Stirring

Operating at 400 volts and 7Hz appears to produces a good stirring action. The surface of the metal remains relatively calm, but with a skimmed bath, a strong body of movement can be seen just under the thin surface layer.
The above pattern is a function of the combined effects of a slower & deeper magnetic field profile and the port geometry. Molten metal from the surface layers is pulled into the upper portion of the port window and jetted back into the main chamber from the lower portion of the port. This results in a slower surface metal velocity and a much higher velocity within the lower areas of the bath. The slower surface velocity and calmer surface gives a reduced tendency for dross formation.

A good measure of stirring performance can be gained from deviations between the surface and hearth temperatures as stirring proceeds. Typical results from measurements taken on site are presented below:

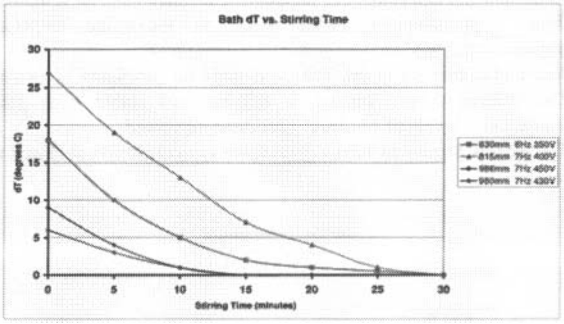
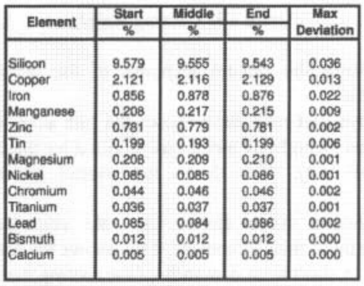


Figure 11. Stirring – Metal Differential Temperatures.

Although the shape of the trial furnace was not designed to make the best advantage of stirring, the homogeneity of the chemical composition of the bath achieved is very good. Bath samples taken at the start, middle and end of casts revealed little variation – typical values are given in the table below



Element	Start	Middle	End	Max
	%	%	%	Deviation
Silicon	9.579	9.555	9.543	0.036
Copper	2.121	2.116	2.129	0.013
Iron	0.856	0.878	0.876	0.022
Manganese	0.208	0.217	0.215	0.009
Zinc	0.781	0.779	0.781	0.002
Tin	0.199	0.193	0.199	0.006
Magnesium	0.208	0.209	0.210	0.001
Nickel	0.085	0.085	0.086	0.001
Chromium	0.044	0.046	0.046	0.002
Titanium	0.036	0.037	0.037	0.001
Lead	0.085	0.084	0.086	0.002
Bismuth	0.012	0.012	0.012	0.000
Calcium	0.005	0.005	0.005	0.000

Figure 12. Typical Chemical Homogeneity through Cast

Casting

The casting function was no doubt the most difficult aspect of the project in which to achieve good results.
The following criteria must be met:

1. Accurate & reliable control of metal delivery to the casting machine.
2. Generate adequate pumping forces to enable the head between furnace bath and invert levels to be overcome (particularly towards the end of the cast).
3. Good resolution of control functions to allow smooth automatic cast starts.
4. Minimise "fallback" of metal and turbulence in the port with subsequent foaming and dross formation.
5. Safe cast abort procedure.
6. Stable & repeatable operation

All the above criteria have been addressed and achieved during the project programme.. A frequency of 6Hz has been found to work well in practice, allowing the furnace to be emptied with less than 100mm metal depth remaining. This is a good result considering it is a retrofit to an existing furnace with no refractory floor slope changes being made to maximize emptying performance.

Automatic cast starts are achieved with no problems or drama. The control during casting is reliable and stable with good resolution – levels of +/- 3mm have been observed.

The graphs presented below give some typical results obtained so far:

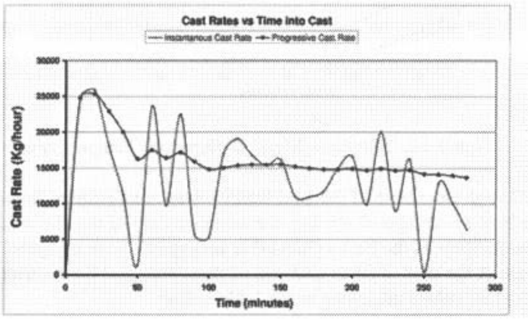


Figure 13. Casting Rates.

Figure 13 shows the system response to the demands of the casting machine.

The progressive cast rate curve shows the rate achieved from the start of the cast (weight of metal cast divided by the time elapsed since start of cast). This shows the overall casting machine performance.

The instantaneous curve shows the rate achieved over the previous 10 minute time increment. This shows the rapid response of the system to short term demands of the casting machine.

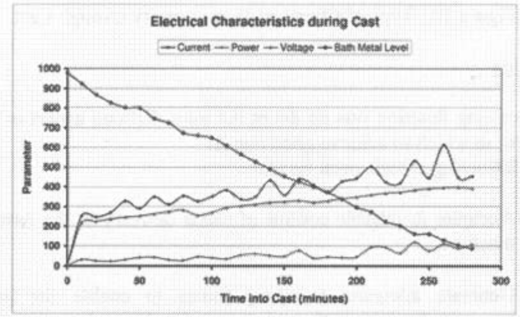


Figure 14. Electrical Characteristics during Cast.

Figure 14 shows how the inductor electrical parameters change through the casting period. A curve of bath metal level is also given.

The above metal level information can also be translated into the graph below (Figure 15) which expresses how the electrical parameters increase with increasing pumping head between furnace and launder invert levels.

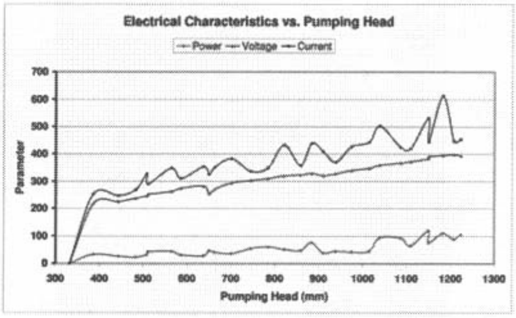


Figure 15. Electrical Characteristics vs. Pumping Head.

A pumping head of over 1.2 metres is being achieved in this particular application. It is possible that greater heads could be reached by modifications to the casting channel geometry and inductor operating parameters.

Summary.

GENIOS has proven to be a very flexible and practical system for both stirring and transferring. It has exhibited impressive performance and reliability in both modes of operation under typical industrial conditions. From VCM's viewpoint, the new system has provided far superior performance, ease of operation and much lower operating & maintenance costs when compared to the original mechanical pump.

References.

1. Apparatus for Inducing Flow in a Molten Material. G. Guest. UK Patent Application 0819685.9, 26th October 2008.

2. International Committee on Non-Ionising Radiation Protection, Guidelines for Limiting Exposure to Time Varying Electric, Magnetic & Electromagnetic Fields (up to 300GHz), 1998.

3. Apparatus for Inducing Flow in a Molten Material. G. Guest. UK Patent Application 1103986.4, 9th March 2011.

Acknowledgements.

The Authors would like to thank the following organisations for their roles in facilitating this paper:

Verdani Carlo Metalli.SpA.
Solios Thermal Ltd.
Fives Solios.