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Technology for Electromagnetic Stirring of Aluminum Reverberatory Furnaces

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Abstract

The benefits of circulation in aluminum reverberatory furnaces are well documented and include higher productivity, and reduced fuel consumption and dross generation. One popular method to achieve the benefits of circulation is electromagnetic stirring. That said, this technology has certain drawbacks preventing its universal acceptance: high capital cost, high operating cost (especially power consumption and maintenance of water cooled copper tubes), reluctance to use water in close proximity to molten metal, and in some cases the inability to operate through full thickness refractory hearths. This paper describes a technology which amounts to the reinvention of traditional electromagnetic stirring devices, effectively addressing all of the above negative aspects of traditional systems. In this paper we will describe how these issues are addressed and results documented in recent installations.

Introduction

It has long been known of the significant advantages of circulating furnaces to improve melt rate, reduce energy consumption, minimize dross formation and obtain excellent chemical and temperature homogeneity. [1,2,3,4,5,9,10,11].

The application of Electromagnetic stirring (EM Stirring) which was initially introduced into the Aluminium industry in the 1960's has grown significantly since the late 1990's. The graph below in Fig 1 shows the huge growth in application of different types of Electromagnetic stirring or pumping technologies to circulate aluminium furnaces reported some years ago [3] but which has continued to grow significantly as the market recognizes the huge benefits to be gained from stirring furnaces.

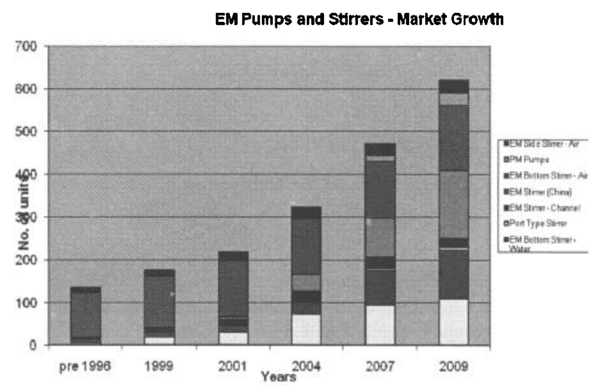

Fig 1 Showing the growth in application of electromagnetic stirring devices since late 1990's.

There are many different types of device available to circulate a furnace today as is shown in the above graph, and all with have more or less the same effect on the operational benefits within the furnace.

Over the past 3 years ALTEK have been working on enhancing the MHD air cooled stirrer technology, which they supply under exclusive licence, to meet these specific operational objectives but also focusing on the importance of the capital cost, operating costs, ease of installation and also reliability of the stirring equipment.

The first MHD stirrers were developed by the MHD Centre in Krasynarsk, Russia [4] in the early 1990's for application throughout the RUSAL (and former SUAL groups). These companies had the desire to circulate their furnaces to achieve the well understood benefits of metal circulation in their melting and holding furnaces. The original MHD inductor stirrer design was developed from 1st principles in Krasynarsk as, having reviewed similar technology on the international market they believed it had some inherent weaknesses. After installing 40 of these stirring units on furnaces throughout Russia, a collaboration was formed with ALTEK to further develop the technology, introduce new design and drive control techniques and introduce the new electromagnetic stirring technology, called SIBER FORCE to the whole world. This was initiated in 2007 with a careful step by step introduction into the wider market.

One of the main driving forces for aluminium operations to consider the air cooled electromagnetic stirring is safety by removing the water cooling requirement of conventional stirring devices from the basement under a furnace or next to a furnace.

EM Stirrer Design

The design of the ALTEK SIBER FORCE electromagnetic stirrer features several fundamentally different aspects and we will discuss each of these in turn below.

Cooling Medium

Due to the design of the inductor coils being made from solid copper bar (not hollow tubing), of certain dimensions, this has the effect of reducing the heating effect of the electrical current applied to the coil. The heating effect from a current passing through an inductor is represented by I^2R, where $R = r/s$ (r = resistvity of copper and s = the surface area faced by the passing current). A larger surface area therefore presents a lower R in this calculation and a reduced heat generation.

This allows for the use of air in a specially applied way within the inductor to be used to remove the lower heat generated by the current applied to the inductor coil.

As is discussed later in this paper, when looking at the operating results, Company A monitored the electrical power consumption at between 3 and 5 kWh per tonne.

A secondary benefit of this type of coil construction also provides for a very long life of the inductor and reduces any risk of serious damage due to overheating of the coil as would occur with a hollow copper tube type inductor coil.
As an example, the oldest inductor installed in 1994 is still in operation today).

Control and Inductor Drive System

The system comprises of 3 key components:-

1. Inductor
2. Control System
3. Cooling Fan

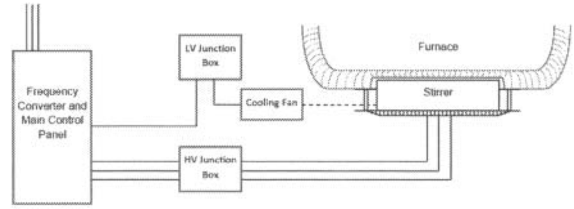

Fig 2 shows the control architecture of a bottom mounted stirrer installation.

There has long been a myth that you need to use huge amounts of electrical energy with this type of technology to obtain the mixing effect within the furnace. This may be the case with alternative designs but with the SIBER FORCE technology this has been overcome significantly reducing the input power requirement

The key focus of this stirring system is to deliver the Lorenz Force within the aluminium bath [3] in the proximity of the stirrer, and due to the viscosity of the liquid aluminium, you get a very effective mass flow of aluminium throughout the whole furnace. Some of the smaller models of SIBER FORCE stirrers are being utilized on furnace capacities of >60 tonnes. The size of stirring model chosen is based upon the following factors:-

1. Size of furnace
2. Type of operation (Melter, holder, liquid, dry hearth)
3. Refractory thickness – to obtain correct penetration of the magnetic flux into the bath.
4. Available space

By using a specially designed and patented technique for driving the inductor coil, a technology utilized in the induction heating industry, allows for a relatively low input current to the control system from the clients facility (the input kVA range is between 80 and 120 depending upon the stirrer model size).

Installation

The SIBER FORCE stirrer can be installed on many different furnace types and is fitted either on the side of the furnace or underneath the furnace hearth in a small basement [7].

Due to the fact the stirrer is air cooled this removes the necessity for costly water cooling systems and associated pipe work. The air cooling is provided by an air cooling fan which can be located nearby to the inductor and connected by air ducting.

The stirrer is separated from the bath through the furnace's refractory thickness and the outer casing in the area of the stirrer is removed and replaced (*as normal carbon steel will not allow* *transmission of magnetic flux*), with a stainless steel plate which allows the magnetic flux to penetrate into the aluminium bath.

Behind the stainless steel plate the existing refractory at its normal thickness remains or if necessary new refractory is installed in that area. This maintains full integrity of the furnace.

There are different stirrer sizes for the different non magnetic gap thicknesses (the thickness of the refractory, insulation, stainless steel plate and air gap) from 350mm (quite typical in a furnace wall) to up to 700mm that may exist on direct dome charge type furnaces.

The control system is fed by a 3 phase 50Hz (or 60Hz) supply sized based on the stirrer model chosen.

On a side mounted installation the inductor is fitted to the furnace by sitting on rails allowing it to be easily moved in and out and then is clamped to the furnace leaving a small 10mm air gap during normal operation.

Fig 3 below shows the installation of a TYPE 400 on the side of a 70 tonne stationary furnace at Company A where the stirrer was rented – hence the temporary location of the cooling fan.

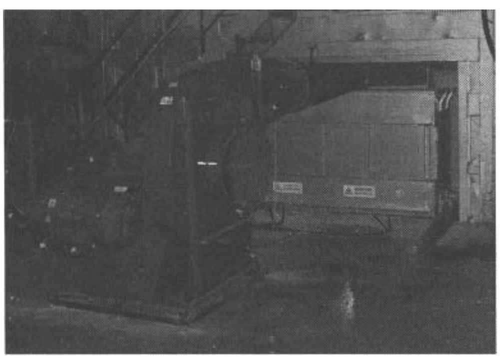

Fig 3 Showing the stirrer installed on the side of a 70 tonne stationary reverb.

On the bottom mounted installation the stirrer can simply reside on a concrete plinth under the furnace allowing the stirrer to locate into the non magnetic stainless steel window or if the basement is deeper, the use of a scissor lift will allow the stirrer to be raised to its operating position or lowered when not in use. Fig 4 below shows the concept on a direct charge dome furnace now being supplied to a customer.

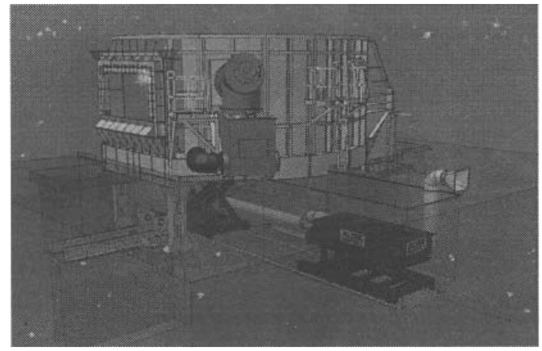

Fig 4 Showing the stirrer and associated scissor lift/trolley mechanism applied to a dome type furnace.

This also allows for the introduction of a trolley system that allows the stirrer to be moved in and out of the basement area or even to operate between multiple furnaces as is shown in Fig 5 below.

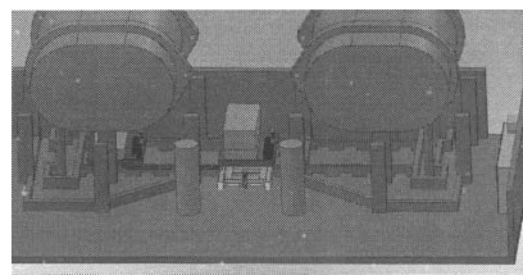

Fig 5 showing the SIBER FORCE installation for multiple furnaces.

Modelling

Before application and if required it is possible to model the furnace to show effectiveness of the stirring effect on homogeneity. The model in Fig 6 below shows cfd modeling of the impact of a side mounted device fitted to a stationary reverb.

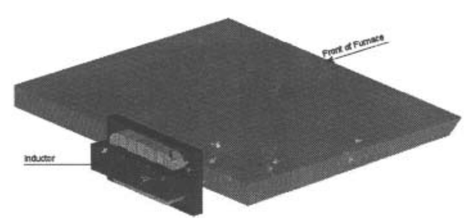

Fig 6 showing the location and preparation of the cfd grid ready for modeling the stirrer on a side mounted application.

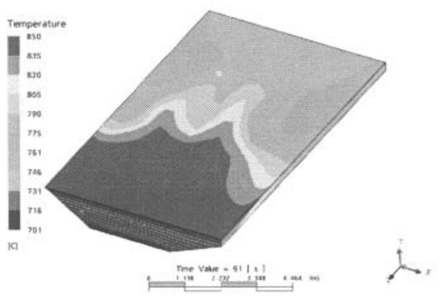

Fig 7 showing the cfd modeling on a large (>100T) tilting type melting furnace to indicate potential temperature homogeneity benefits.

Operational Benefits

A TYPE 400 side mounted SIBER FORCE stirrer was installed on the side of a 70 tonne stationary reverbatory furnace at Company A in June 2009. A production monitoring study was performed in May 2010 by Company A.

To assess the effect of stirring a protocol was put in place designed to reduce the wide variability in the melting process, whether it be intrinsic to production (charge composition,) or to the installation (combustion settings, unidentified degraded operating modes) or of human origin (working practice).

An alternating sequence of heats with and without stirring were carried out over 5 days at the rate of 3 to 4 heats per day. A 3xxx alloy series was used throughout the casting run.

Production personnel (charging and melting operatives) were asked to observe particular operating procedures which we considered key to the variability of the melting process:

- Charge loading: in a single operation with a minimum crown temperature of 1050°C
- Bath breaking: breaking at a minimum crown temperature of 1100°C
- End of casting regulation: 730°C

The furnace operators were also asked to take particular care to open the furnace doors only when strictly necessary, as opening the doors is associated with major energy loss.

A summary of the results of the study are shown below.

Melt Rate

The melting rate represents the tonnage melted on average by the furnace in one hour. It is calculated by dividing the tonnes charged by the melting time between the end of loading of the charge and the moment when the liquid bath reaches a temperature of 730°C. The opening times of the furnace doors are determined.

Fig 8 below shows the gross results in the form of a time chart and the figure on the right is a statistical representation after correction for the effect of the initial temperature of the furnace. On average, the melting rate increased by from 10.7 to 12.8 t/h (+20%) with the stirrer running (highly significant effect, risk <1%). **The difference (with stirrer - without stirrer) is +2.1 ± 1.4 t/h.**

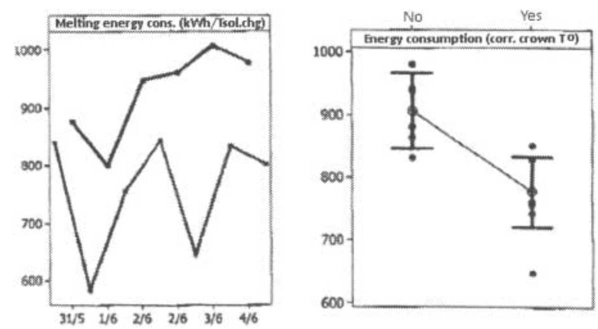

Fig 8: Showing time chart of melting rate. and Statistical average melting rate

Energy Saving

The impact on the quantity of energy needed for melting only was assessed, and the results shown below in Fig 9 i.e. from the end of charging up to the transfer temperature (730°C). Analysis of the data indicates a significant reduction (risk <1%) in energy consumption from 906 to 777 kWh/t (–14%). **The difference (with stirrer – without stirrer) is –130 ± 90 kWh/t.**

The specific consumption of the stirrer was measured at between 3 and 5 kWh/t.

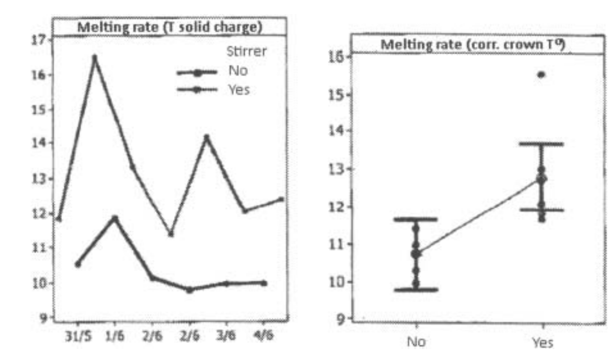

Fig 9: Time chart of specific energy consumption and Average specific energy consumption corrected for the effect of crown temperature.

Dross Generation

The weight of the slag after each skimming of the bath was measured. Over the week of the tests, and taking into account the composition of the charges (small amount of compact materials in particular), it was found little slag variations. Fig 10 below compares the weighed quantities of slag with and without stirrer. It is inconclusive in terms of identifying a stirrer effect. In order to reach a definitive conclusion it would be necessary to compare complete runs with full melts (70t) over a longer period with drainage of the furnace, and to determine a full material balance.

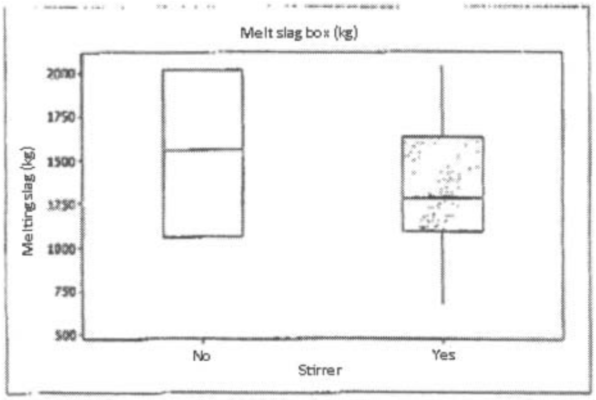

Fig 10: Quantity of slag formed in operation with and without stirrer

It is reported [6] that a large impact on dross generation is the ratio of solid to liquid charge. The more solid charge (less liquid charge added) the higher the dross generation which is as you would expect as most of the dross is generated in the early part of the cycle on a dry hearth furnace operation as a consequence of the exposed scrap to the burners.

Other similar studies with electromagnetic stirrer have demonstrated there can be a reduction of dross formation with a stirrer application [6].

Summary

Due to the simplicity of design the capital costs for installation of the equipment can be lower than a water-cooled stirring technology whilst also removing the water from the proximity of the melting furnace.

With the solid design of the stirrer and specially designed control and drive system, low operating costs through low energy consumption can be achieved.

As the study at Company A's facility has shown they were able to show that electromagnetic stirring has a significant measurable effect on the melting performance of one of their melting furnaces.

The performance was quantified under test conditions (controlled pre-heating of the furnace, good operating practice).

In terms of **intrinsic melting rate, an improvement of 2.1 (±1.4) T/h** was observed.

	Specific melting rate (kWh/t)
Average without stirrer	10.7
Average with stirrer	12.8
% with/without stirrer	+20% (+6%; +34%)

In terms of **energy consumption** in the melting phase, **an improvement of 130 (± 90) kWh per tonne** was observed (the energy consumption of the stirrer in the order of 3 kWh/t to be deducted from this figure).

	Specific melting energy (kWh/t)
Average without stirrer	906
Average with stirrer	777
Grouped standard deviation	66
% with/without stirrer	-14% (-4%; -24%)

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