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Improvements in LiMCA Technology: Introducing the LiMCA III

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Abstract

The LiMCA measurement principle has proven to be a robust approach for measuring solid inclusions in molten aluminium in various industrial conditions thus providing a quality indicator for metal cleanliness of aluminium alloys.
Improvements in electronics, equipment configuration and data processing have made the LiMCA much more usable in industrial process environments. This paper reviews some of these advancements and how they affect the ability to use LiMCA in industrial environments. New perspectives on further improvement of the technology for the next generation LiMCA III will be presented.

Introduction

Energy efficiency mandates in industry and transportation have been driving the adoption of lightweight materials with stringent mechanical qualities. Aluminium alloys are increasingly being used to meet these requirements and this has driven the need for very tight quality control.

In the case of aluminium one of the most important parameters is metal cleanliness defined as the number and size of solid inclusions per unit volume.

These solid inclusions can degrade mechanical qualities and spoil surface finishes. They can manifest as small holes, tears and defects on polished surfaces.

In order to address this challenge the aluminium industry has developed processing steps to clean the molten alloys by removing solid inclusions [7] and various measuring techniques to evaluate their effectiveness [1-6, 9-13].

The LiMCA technique developed in the early 80s remains today the only commercially deployed means of determining molten metal cleanliness in-line and in real time. Over the past 30 years, multiple generations of LiMCA instruments were developed and commercialized [8, 9, 14]. This paper will review the main characteristics of the previous generations of LiMCA and explain the advances that went into the development of the latest LiMCA, the LiMCA III, which is being launched this year at TMS.

Measurement Principle

The solid inclusions found in molten aluminium are non-metallic compounds such as aluminium and magnesium oxides, borides, carbides, nitrides and fluorides. The LiMCA instrument takes advantage of the fact that the inclusions are much less electrically conductive that the molten aluminium metal to detect their presence.

This is accomplished in LiMCA instruments by using a vacuum to pull the molten aluminium into an aluminosilicate glass probe through a 300 micron aperture. While the molten aluminium is flowing through, an electric current is maintained across the aperture. If an inclusion is pulled through, a voltage spike occurs due to the change in resistivity. This is known as the Electrical Sensing Zone technique or Coulter principle [14].

The duration of the voltage spike is equivalent to the transit time of the inclusion through the aperture. The magnitude of the voltage spike is proportional to the volume of the particle and can be approximated by the following equation:

$$\Delta V = \frac{4I\rho d^3}{\pi D^4}$$

Where:

ΔV is the amplitude of the voltage spike measured (V)
I is the electric current (60 A)
ρ is the electrical resistivity of the fluid ($25\text{x}10^{-8}\Omega$-m for pure Al)
d is the equivalent spherical diameter of the inclusion particle (m)
D is the aperture diameter ($3\text{x}10^{-4}$m for a standard LiMCA probe)

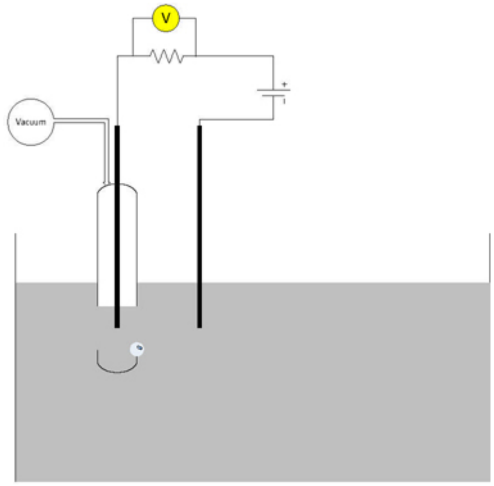

Figure 1: LiMCA measurement principle

By measuring the size and duration of the voltage spikes over time it is possible to build up a distribution of the number of inclusions of different sizes per unit volume.

Early LiMCA instruments

The first instrument to use the LiMCA principle, the LiMCA I was developed at the Arvida Research & Development Center of Rio Tinto Alcan in 1987. This huge system was mostly used as an R&D tool for understanding aluminium processing. It demonstrated that it was possible to measure 20 microvolt signals, corresponding to 20 micron inclusions in molten aluminium at 700°C in the electrically noisy environment of an aluminium processing facility.

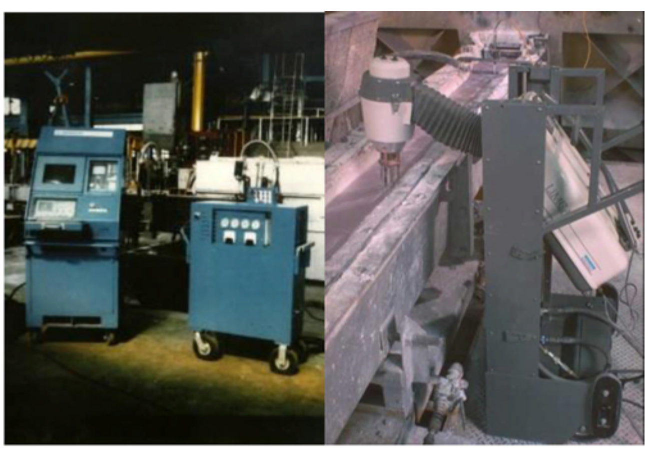

Figure 2: The LiMCA I and LiMCA II instruments

The LiMCA made the transition to the production floor with the commercial launch of the LiMCA II in 1994. This was the first generation of instrument available to the aluminium industry. The LiMCA II was a portable system made possible by the advent of digital electronics.

The early LiMCA systems used high currents to generate strong signals and rechargeable batteries to generate ultra-low noise DC. This was required to detect the microvolt level signals generated by the passing of inclusions.

Over 20 years of utilization by most aluminium producers worldwide, the LiMCA II [8] instrument has proven to be very successful and adaptable to monitor the metal cleanliness in a very wide range of process configurations. It is still widely used, for process understanding and metal treatment technology development.

The LiMCA II uses old generation of Ni-Cd batteries to generate the electrical signal. These batteries require regular replacement and maintenance to keep the LiMCA II operating at peak performance.

The LiMCA CM

The permanently mounted LiMCA CM (Continuous Monitoring) was introduced in 2004.

Figure 3: The LiMCA CM instrument

It was designed for autonomous operation with a measuring head that lowers itself automatically into the molten metal and standard networking features allowing it to be connected to the plant control system.

The LiMCA CM uses more modern electronics for increased reliability. It uses ultra-capacitors instead of batteries to provide low noise DC current and a single compact electronic card.

While the permanently mounted design of the LiMCA CM makes it ideal for process control, it is difficult to use for process investigation because it cannot readily be moved to sample different locations along the casting line.

Introducing the LiMCA III

ABB in partnership with RioTintoAlcan, Alcoa and Hydro have rethought the LiMCA instrument from the ground up in order to introduce the LiMCA III here at TMS 2015.

In designing the LiMCA III, the best characteristics of the highly successful LiMCA II in regards to mobility and versatility where retained and improved on. The LiMCA III design also benefits from the advancements made in the LiMCA CM and from advancements in IT and electronics technologies that have occurred since the launch of the LiMCA CM 10 years ago.

The most important of these advancements is in the LiMCA III electronics where a new patented AC measurement principle [15] is implemented. The AC measurement principle eliminates the need for carefully conditioned DC power and dramatically reduces current requirements while increasing the robustness against electromagnetic interference.

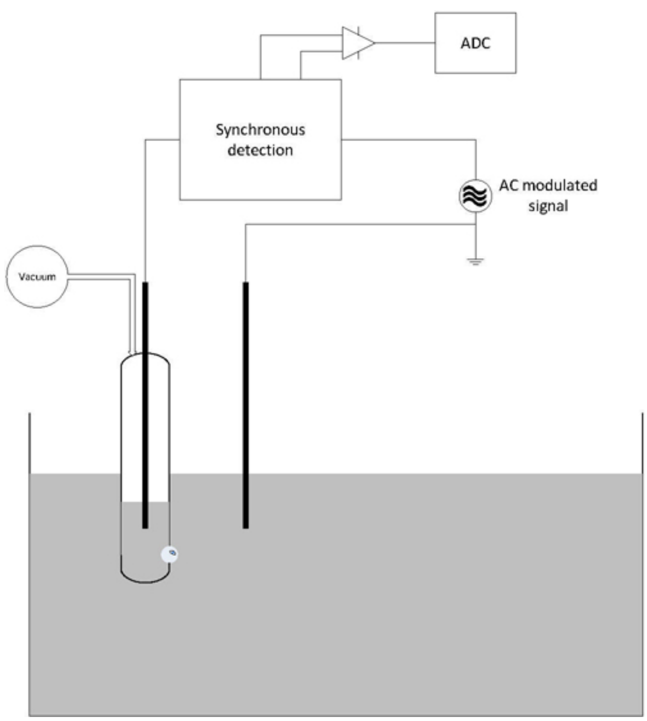

Figure 4: The LiMCA III measuring principle

In the LiMCA III instead of looking for a voltage pulse created by the change in the resistance associated to the passage of an inclusion we look for a change in amplitude of the sine wave associated to the AC excitation.

Any electrical noise or signal that is not modulated at the carrier frequency is eliminated, leaving only the contribution of the inclusion measurements.

Because low frequency noise and external electromagnetic perturbations are rejected by the synchronous detection of the voltage changes, the LiMCA III can detect much smaller voltage changes and therefore operate at lower power.

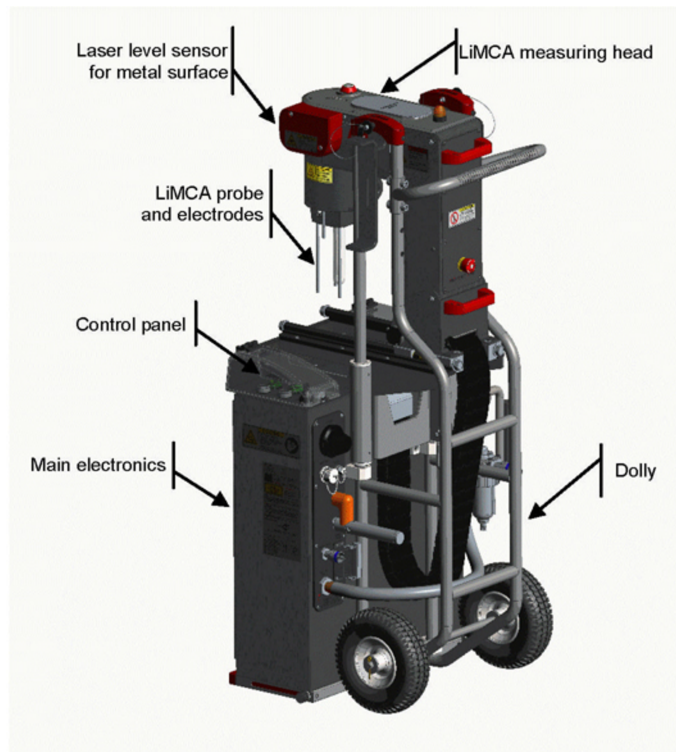

Figure 5: Schematic of LiMCA III instrument

The characteristics of the LiMCA III design will contribute to making it easier to use, more robust and more versatile than its processors the LiMCA II and LiMCA CM:

- The LiMCA II and LiMCA CM are the industry golden standard for inclusion measurements. The LiMCA III was therefore designed to provide the same readout and inclusion counts under the same conditions. The equivalence of measurements was extensively validated firstly by using an independent inclusion signal simulator and then by testing in a controlled batch of real molten metal in a small oven.

- In addition to providing the same measurements, the LiMCA III uses the same robust industry proven electrodes and probes as the LiMCA CM and LiMCA II. This makes management of consumables very easy when operating a mix of LiMCA III and older LiMCA instruments.

Finally the LiMCA III uses the same proven ruggedized probe holding mechanism as the LiMCA CM which was a great improvement over the LiMCA II probe holder.

Figure 6: Validation testing of LiMCA III in small scale oven

- The LiMCA III replicates the compact lightweight mobile design of the LiMCA II allowing it to be placed on the casting line walkways of most aluminium plants while addressing some of the common complaints and limitations of the LiMCA II

- When the LiMCA III measuring head is lowered nothing sticks out the back; the LiMCA II pivots backwards and could sometimes block walkways while it was in use.

- The LiMCA III measuring head positioning in molten metal is more flexible than for LiMCA II. The LiMCA III has better clearance, more positioning flexibility and a wider range of motion than LiMCA II.

- Furthermore the LiMCA III has a laser level sensor that allows it to automatically raise or lower the head to follow the level of the molten metal.

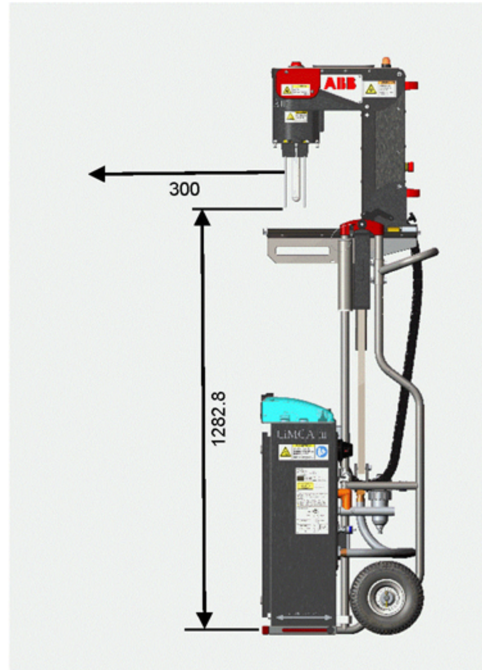

Figure 7: Maximum vertical position of LiMCA III measuring head

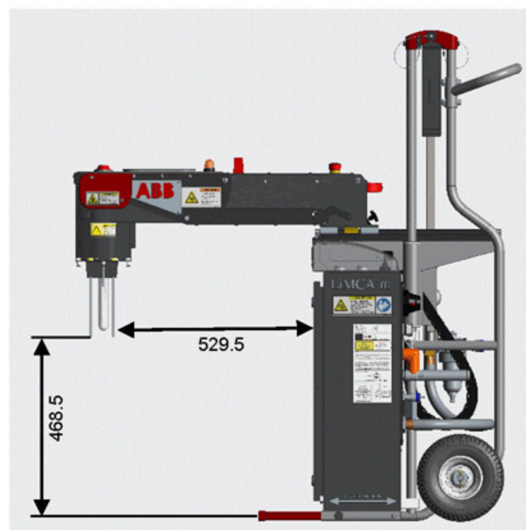

Figure 8: Maximum forward reach of LiMCA III measuring head

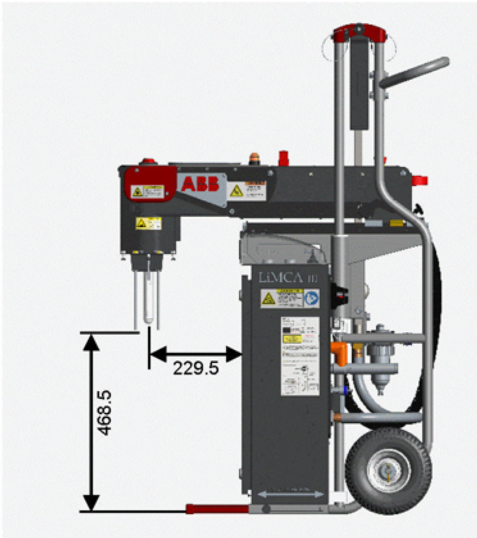

Figure 9: Minimum forward reach of LiMCA III measuring head

- LiMCA III is lighter and has a lower center of gravity than LiMCA II making it more stable and easier to maneuver.

- The LiMCA II was able to measure inclusions in the electromagnetically noisy environment of an aluminium plant by making use of rechargeable NiCad batteries. The LiMCA III was implemented using an AC modulated signal to achieve even better electromagnetic noise rejection. This eliminates the need for batteries, which on the LiMCA II have to be replaced every year.

- The LiMCA III was designed in a modular way using industry standard subassemblies in order to greatly simplify service and improve reliability. Consumables are designed for easy replacement.

Figure 10: Replacement of thermocouple on LiMCA III measurement head

- The LiMCA III makes use of a standard web based HMI that can be run on most computers and tablets that have a compliant web browser.

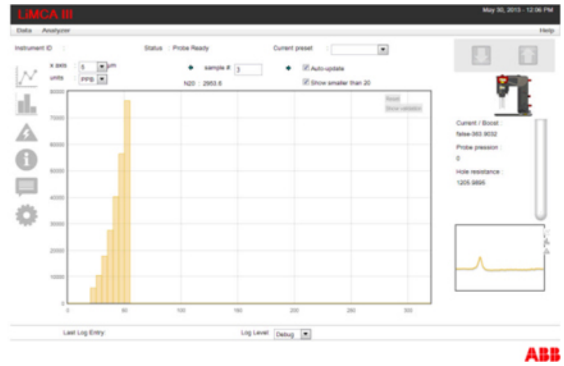

Figure 11: LiMCA III web based HMI

- The LiMCA III uses of industry standard PLC based controllers, making it reliable and easy to maintain and extend.

- The LiMCA III has a built in networking architecture that can be customized to connect to customer proprietary control networks.

Conclusions

The adoption of LiMCA technology in the form of the LiMCA II or LiMCA CM analyzer systems in the aluminum casting industry has driven the development of a whole new generation of treatment equipment to reduce and control inclusions and allowed the development of consistent high yield specialty materials that would be impossible without tight control over inclusion sizes and quantities.

The advent of the LiMCA III will further accelerate adoption of LiMCA technology by providing the same unique in-line and real time readings in a more reliable and user friendly manner.

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