

Implementation of an alternative matte-level measurement solution at Lonmin Marikana Smelter Division for improved process monitoring

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Abstract – Accurate control of matte levels during primary matte smelting operations is desirable in order to improve process decision-making. High matte levels in the vessel could have disastrous consequences, particularly in the new generation of intensive smelting furnace with deep-cooled copper coolers. Knowing when to commence tapping and a better understanding of melt times can only be improved if the furnace levels are monitored correctly.

At Lonmin Marikana Smelter Division it has long been understood that the matte level information being provided by the manual sounding bar is only as good as the operators' following of measurement procedure, their skill in assessing what the sounding bar is displaying, and their individual interpretation of what they are looking at.

This paper sets out to show how this problem was identified as an area of major concern to the plant, how a solution was sought and how an electromagnetic measurement system was installed as an alternative measurement to the matte sounding bar system.

Other areas discussed in the paper are the difficulties to be overcome when first installing new equipment and how these teething problems were solved by close co-operation between Lonmin and equipment suppliers, which led to some design modifications to the delivery system.

In conclusion the paper discusses the results between the electromagnetic measurement and the manual sounding measurement and how best to integrate the generated data into the plant's process control system for improved decision making.

INTRODUCTION

Lonmin Marikana is a platinum smelting and refining plant. The main smelting furnace is a 3-electrode arc furnace; it uses Söderberg electrodes capable of producing 22.5 MW power. However, owing to running problems, the furnace is generally run at about 15 MW and can at times be run as low as 12.5 MW.

BACKGROUND

Lonmin's main furnace extracts a mix of metals from enriched ore. This mix contains mostly copper, nickel, iron and sulphur, but even small quantities of platinum, palladium and other precious metals.

In order to operate the furnace at optimal capacity while ensuring a high level of safety for personnel and equipment, a good knowledge of the matte level is required. Until recently, the most accurate and consistent way to confirm predicted matte levels has been the use of sounding bars. Unfortunately, experience has shown that the reliability of sounding-bar-based matte measurements is not always accurate owing to a number of factors. Therefore, we decided to seek alternative measurement techniques.

The search for alternative techniques brought the smelter team into discussions with a Swedish technology company, Agellis Group AB, which had been working for many years providing high-accuracy measurement systems for the steel industry. In discussions, the smelter team realised that one of the Agellis systems, an electromagnetic sensor probe that detects conductivity, could be modified to provide the type of measurement we required.

Agellis engineers, who had previously successfully tested their system in both copper and silicon plants, made the necessary modifications to suit our specific furnace conditions. Lonmin decided to test the new technology, called the EMLI¹ ELP² measurement system, on its main furnace.

SYSTEM INSTALLATION

The EMLI ELP system is designed to be used in combination with a full-lance carriage mechanism which provides an easy-to-operate, accurate and very reliable delivery system for any furnace measurement probe. A stylised lance-carriage installation arrangement can be seen in Figure 1.

Other benefits that can be derived from a lance-carriage mechanism for delivering the EMLI matte-level probe are possibilities for measuring slag thickness, bottom build up and temperature, and for taking metal samples.

¹ The *ElectroMagnetic Level Indication* system is the multi-purpose core of a wide range of liquid-metal-measurement solutions, including furnace-level profiling.

² The *Electromagnetic Lance Profile* measurement system is a furnace-level-profiling extension of the standard EMLI system architecture.

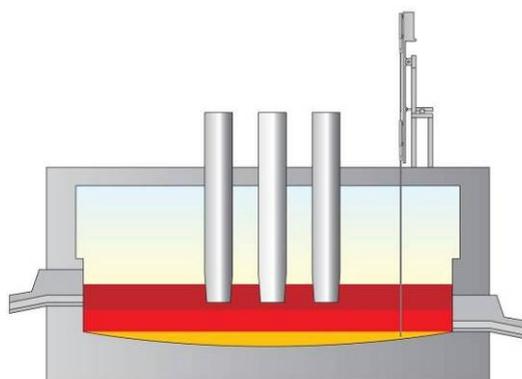


Figure 1: ELP system positioning

However, the ELP DW Trial system was not lance-carriage operated and consisted instead of a lance complete with a sensor probe which can directly replace any sounding bar system. It has a draw-wire unit attached as part of the measurement loop to be able to ascertain the distance the lance travels into the furnace (see Figure 2).

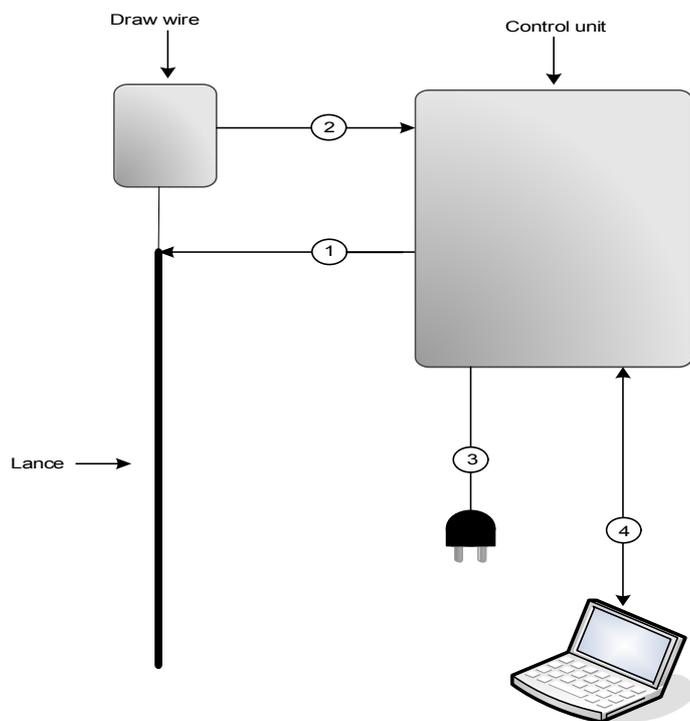


Figure 2: ELP connections

The ELP lance can be attached to the same winch delivery cable as the sounding bar or can be given its own winch and furnace access port. This was sufficient to provide matte-level detection only, as all other measurement capabilities require the full lance-carriage implementation.

The length of the lance was decided upon following discussions and inspection of drawings and photographs of the furnace. An exchangeable electromagnetic sensor was installed in the lance tip. A high-temperature cable connected the EM sensor to the control unit, which also supplied the sensor with power. The

steel ELP lance was protected from high furnace temperatures by a set of disposable paper shields. In all other respects, the lance was operated in the same way as a traditional sounding bar. The lance was attached to a winch capable of a steady 15 m/min. The installation can be seen in Figure 3.

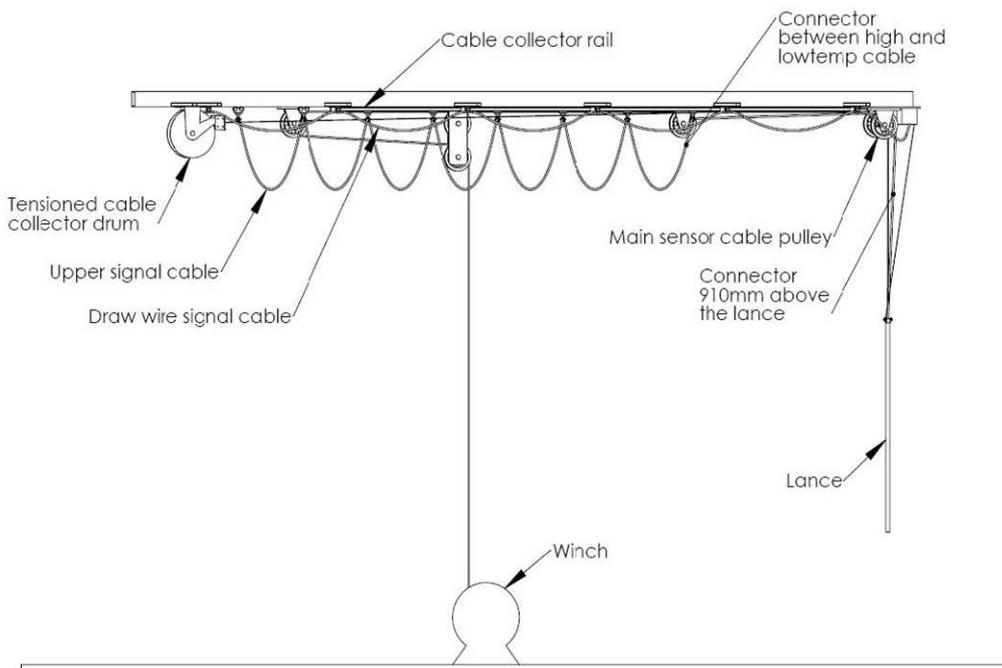


Figure 3: System configuration

Figure 3 illustrates the installation of the lance, winch and sensor-cable retraction system. These components were all installed on an upper floor so that the lance would hang directly over a furnace access port. Initially, the smelter team intended to replace the existing sounding bar temporarily with the ELP lance. However, the the team decided that it was better to provide a completely separate access port alongside the existing one with the ELP having its own winch delivery. This gave us the possibility of continuing our normal furnace level measurements while at the same time providing control measurements to compare with the ELP-provided data.

The pictures in Figure 4 and Figure 5 were taken on the upper retractor floor and the furnace roof, respectively. They show the ELP lance installed in parallel with the pre-existing sounding bar.

SYSTEM COMMUNICATIONS

The Agellis EMLI ELP system is integrated with our PLC via ordinary 4–20-mA lines. Figure 6 illustrates the general connection. It shows how the *control unit* acts as a central hub for all the main signals. The *control unit* is currently configured to deliver the processed electromagnetic sensor signal and the real-time draw-wire height to the PLC. When the system is fully automated, these twin 4–20 mA signals will be used to determine the matte height.

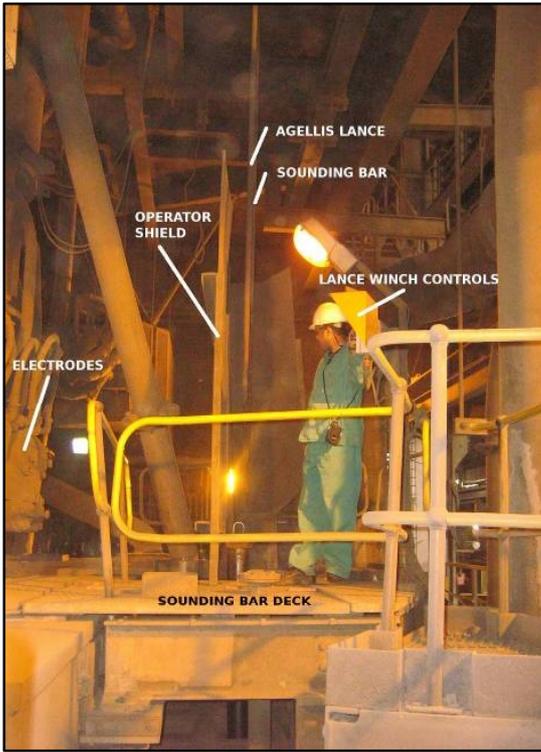


Figure 4: Upper retractor floor



Figure 5: Furnace roof

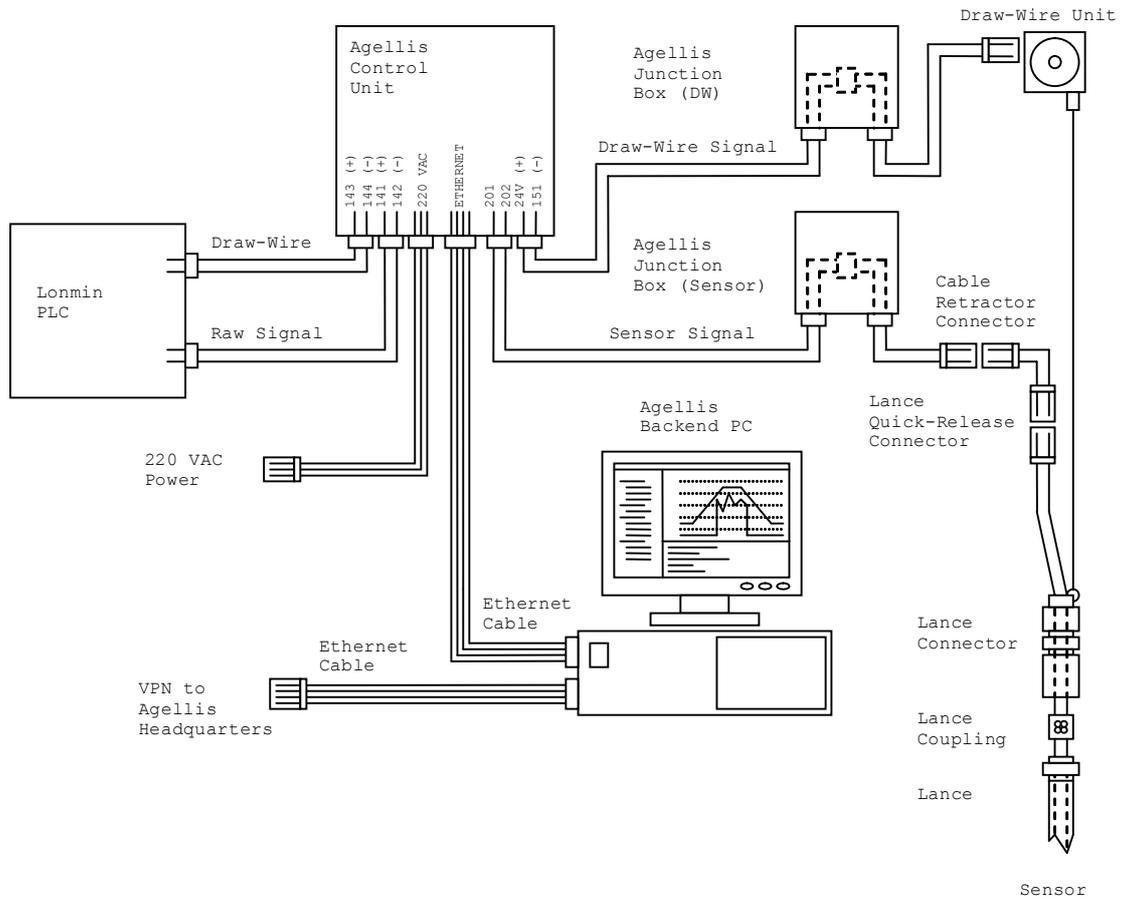


Figure 6: Symbolic EMLI-ELP connection diagram

Currently, manual matte calculations are run with the 1% rule based on the same signals logged on the Agellis backend PC.³ This PC is not usually required for ELP operations, but it is useful for logging signals, remotely adjusting *control-unit* settings, and viewing the ELP logs for manual analysis.

This PC is also useful for determining live *zero-point*⁴ calibrations of the draw-wire height-measuring system. During the trial the draw-wire measure was calibrated over a 4,300 mm distance and found to be accurate. It is important to check the draw-wire *zero point* from time to time as changes to the furnace distances may easily go unnoticed and lead to measurement drift.

SENSING TECHNOLOGY

The Agellis EMLI ELP system works on the principle that conductive materials affect an electromagnetic field. By applying an electromagnetic signal of a particular frequency to a sensor coil embedded in a protected lance probe, one can measure an effect when the probe reaches the highly metallic matte in a furnace. Figure 7 illustrates the relationship between the sensor signal and the encountered material.

ELP OPERATION

The operation of an ELP lance is very similar to the operation of a sounding bar. The lance is fitted with protective covers and lowered into the furnace at a steady rate and then raised once the bottom has been reached. The main difference is that the level readings are extracted digitally by the main *control unit* by correlating changes in electromagnetic conductivity with distance into the furnace. Measurements generated in this way are both accurate and precise as they do not rely on the subjective evaluation of different operators. This gives more repeatable and reliable measurements than the traditional sounding bar.

Electronic Testing

Once the lance components had been assembled and the sensor-cable retraction system was installed, the *control unit* was hooked up to a logging computer and the digital components of the system were diagnosed as fully operational. The *control unit's* settings were adjusted to better suit the local electronic noise levels and cabling lengths. Once this was completed, we proceeded to test the mechanical components.

³ The Agellis backend PC is located in an office on the furnace roof level.

⁴ The zero point is the distance from the draw-wire device to the top of the furnace access port. This value is used to determine the matte level from a sampled draw-wire reading.

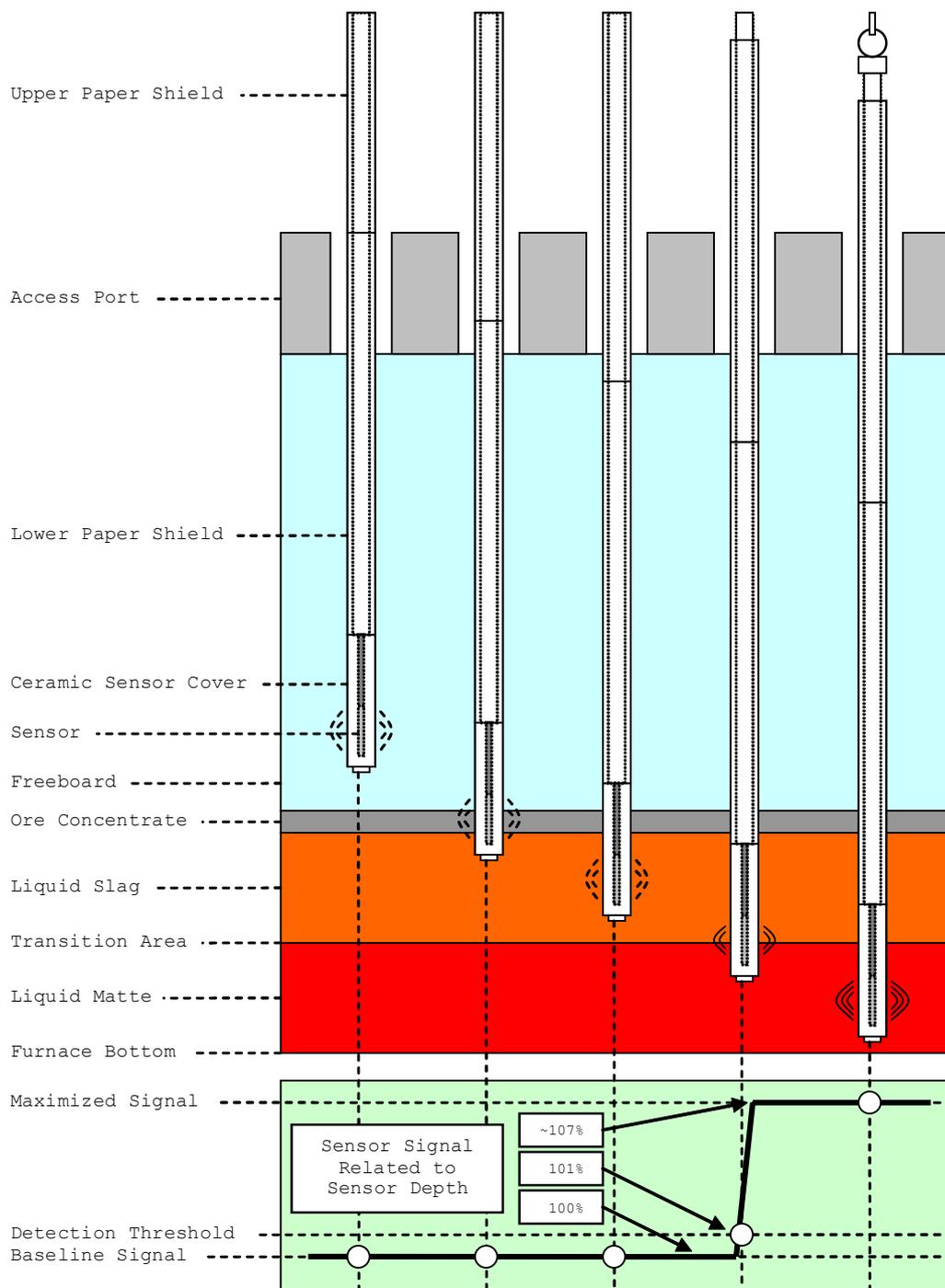


Figure 7: Sensor signal output related to sensor depth

Mechanical Testing

As the high temperatures in the furnace could burn quickly through most protective materials, it was important to ensure that the lance winch was functioning correctly. The protective lance covers were tested to ensure they were able to withstand high temperatures long enough for the electromagnetic sensor not to overheat. After some initial winch difficulties, a few attempts were made to lower the lance into the furnace. As the furnace had been powered down for several hours at that time, it proved difficult to break through the crust on the surface of the slag, even with the traditional sounding bar.

However, after the furnace was running again at normal power, there was no problem entering the slag.

Examination of the ceramic and paper shields showed a surprising lack of damage to the covers. Although the single-use, ceramic sensor cover was completely covered in slag, it had easily withstood attack and the sensor remained cool behind it. The lower paper tube was slightly burnt at the lower end, but the upper tube was in perfect condition. We concluded that the upper tube would likely not need replacing and the lower tube could be used twice before replacing. Satisfied with the mechanical system, we began the initial matte detection trial.

Detecting matte in the furnace

The effects of the actual electromagnetic properties of the liquid matte were unknown at the beginning of the trial. However, as the electromagnetic sensor was functioning perfectly, no major difficulties in detecting the slag-matte interface were expected. Unfortunately, owing to a cable restriction on the upper cable retractor floor, several unsuccessful attempts were made before the problem was identified and the faulty cable extended. The next attempt immediately detected matte at the expected level with an exceptionally strong and clear signal response.

ANALYSIS OF THE RAW DATA

The trial proceeded with the Agellis system detecting matte on every successful dip. Furnace power and electromagnetic interference did not appear to adversely affect measurements. The logged signals were examined to determine the best matte-level determination algorithm. Figure 8 illustrates the first successful detection of matte. The “mountainous” peak (in blue) in the diagram represents the depth of the lance in millimetres. The largely flat signal (in red) with a near vertical central peak represents the sensors signal as it passes down and then up through the furnace. In subsequent measurements, adjustments and improvements were made to cabling, winch electrics, sensor signal filtering and digital-processing settings to optimize the received data. Figure 9 illustrates a clearer immersion as a result of these efforts.

The initial measurement (Figure 8) gave a 6.6% signal increase from baseline on entering matte. The subsequent measurement (Figure 9) gave 7.3%. Generally, the matte detection spike was ~7% above baseline for most immersions. The raw results were consistent, and so we proceeded analysing the signal. We discovered that the smaller signal spikes represent the effect of the sensor passing through a 2-m-long metal-furnace-entry-port tube. After the probe enters the furnace proper, the interference caused by the tube diminishes and the sensor signal flattened out.

The sensor is optimized to detect only metal-rich materials. Therefore, it reacts only slightly on entering the concentrate ore and then the molten slag. When the sensor passes through the slag-matte boundary the electromagnetic

conductance jumps suddenly, producing a higher signal current. This sudden jump makes for a very accurate determination of the slag-matte boundary level.

The next challenge was to convert this detected threshold into a more useful matte-level measurement by correlating it the levels of the furnace tapping holes. This is essential in order to make practical use of the data for taking process decisions on when to tap matte.

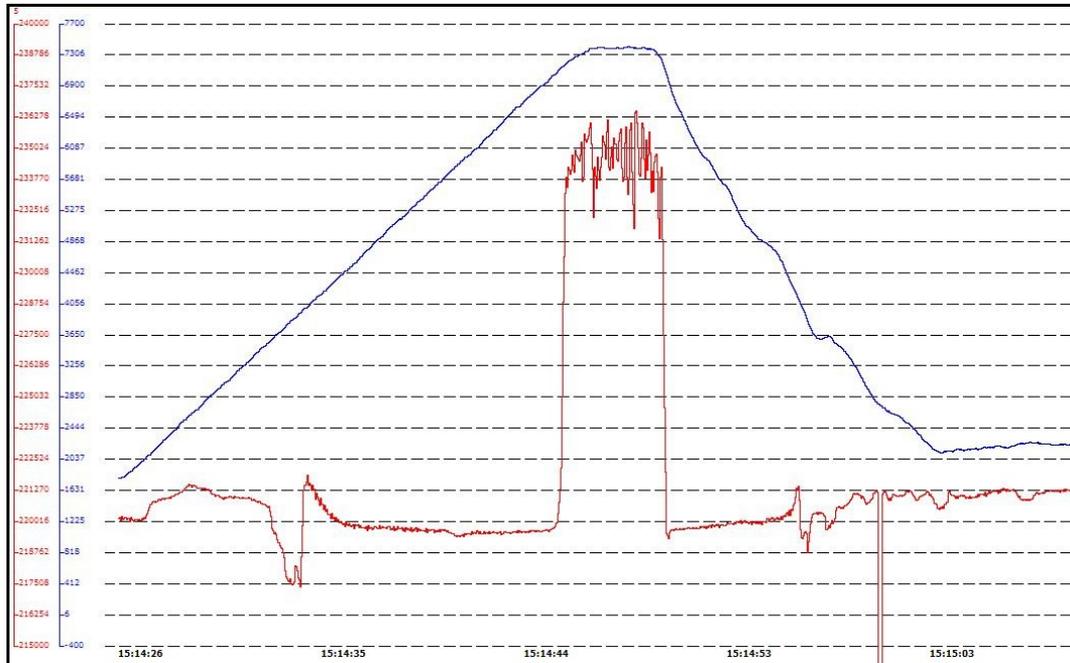


Figure 8: The first successful measurement

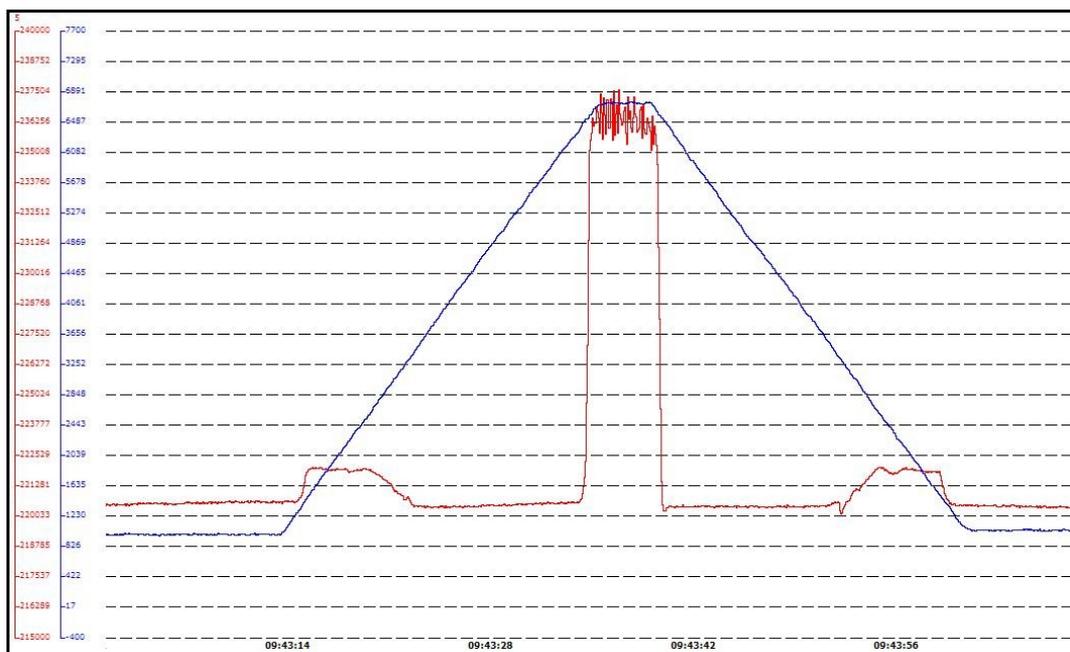


Figure 9: Subsequent improved measurements

THE MATTE-LEVEL ALGORITHM

It was demonstrated that a simple, objective, mathematical approach could be used to convert the sensor signal provided by Agellis to a matte-level-height indication. This is essential for digital automation of the matte-level determination. The algorithm used to determine the matte level is as follows:

1. The sensor is lowered past the furnace entry port until the sensor signal flattens out
2. The flat background sensor signal is measured
3. The detection threshold is calculated as 101% of the background signal
4. Once the signal increases to the threshold level, the current draw-wire reading is sampled
5. The draw-wire sample is then converted to a tap-hole relative matte level by a simple formula, namely,

$$Level_{matte} = Depth_{furnace} + Furnace_0 - Entry_{matte} \quad [1]$$

- where
- *level* is the desired matte level
 - *depth* is the virtual depth of the intended furnace, including all mechanical offsets – determined as 5,460 mm in this case
 - *furnace* is the draw-wire zero point, calculated as the roof of the furnace; it was 1,300 mm at time of commissioning
 - *entry* is the sampled draw-wire reading

The algorithm was used to generate all matte-level measurements from the raw data. It is consistent, reliable and easy to implement in a back-end PLC system. Figure 10 provides an example of a manual analysis.

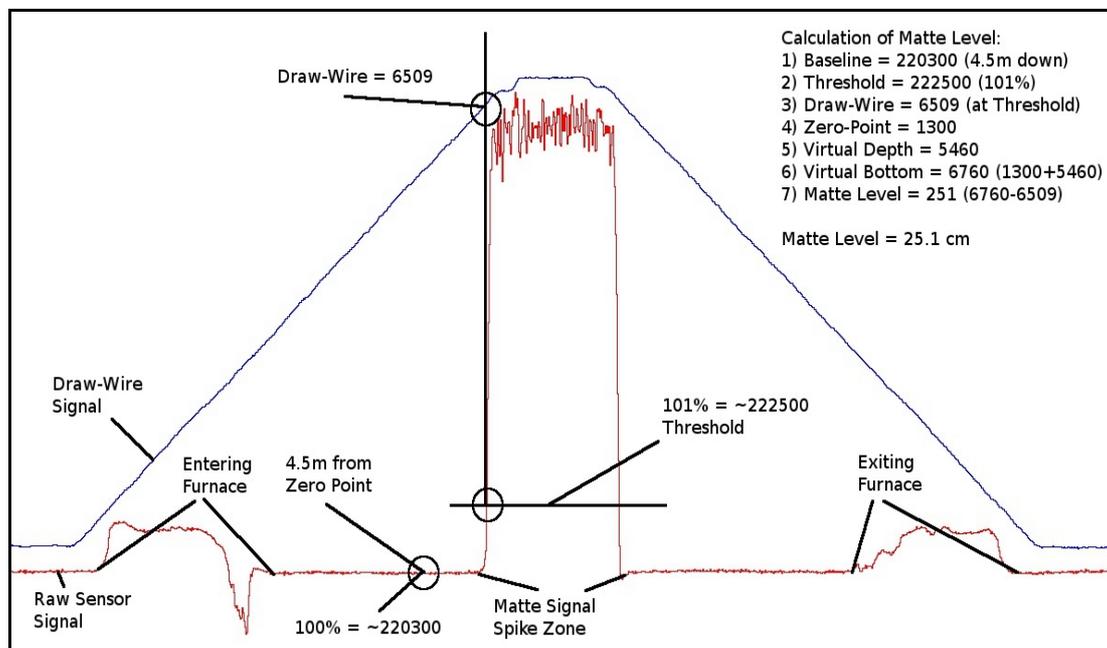


Figure 10: An example of matte-level determination that uses the 1% rule

MATTE-LEVEL EVALUATION

Measurements were taken over a three-day period with both Lonmin and Agellis personnel present. The team started by conducting systematic dips in pairs before and after tapping, as well as systematic dips in pairs during non-tapping periods. The Agellis EMLI ELP levels were calculated and compared directly with manual sounding bar measurements taken at the same time. Logging and analysis were carried out at the *management unit PC*. The following points were noted:

1. All immersion sequences were consistent – a matte level was determined each time
2. The ELP system worked equally reliably with furnace power on or off – it was not adversely affected by electromagnetic noise
3. The ELP system detected changes in tapping level of ~18 mm each time
4. The ELP system detected an increase in matte level over time
5. The ELP system levels matched the Lonmin sounding-bar levels
6. The ELP lance ceramic and paper covers protected the lance and sensor well, despite multiple sequential dips without letting the sensor cool down between dips

Determined matte levels – Day 1

Measurements were taken in pairs to determine consistency and repeatability. Generally, the repeatability was very good with precision around $\pm 10\text{mm}$. The rises and falls in levels coincided well with known tapping events and interims. The measured matte levels are listed below in Table I.

Table I: Matte-level measurements for day 1.

#	Comments Day 1	Day (YY-MM-DD)	Time (HH:MM)	Zero position (mm)	Virtual bottom (mm)	Matte entry (mm)	Matte level (mm)
9A	Could not reach bottom	2010-10-12	09:26	1300	6760	N/A	N/A
9B	Successful dip	2010-10-12	09:33	1300	6760	6509	251
9C	Successful dip	2010-10-12	09:37	1300	6760	6504	256
10A	Successful dip	2010-10-12	09:43	1300	6760	6528	232
10B	Successful dip	2010-10-12	09:47	1300	6760	6535	225
11A	Successful dip	2010-10-12	10:38	1300	6760	6508	252
11B	Successful dip	2010-10-12	10:42	1300	6760	6528	232
12	Successful dip.	2010-10-12	10:55	1300	6760	6510	250
13A	Successful dip.	2010-10-12	11:09	1300	6760	6522	238
13B	Successful dip	2010-10-12	11:13	1300	6760	6501	259
13C	Successful dip	2010-10-12	11:17	1300	6760	6520	240
14A	Successful dip	2010-10-12	11:26	1300	6760	6524	236
14B	Successful dip	2010-10-12	11:29	1300	6760	6520	240

It was noted that the draw-wire zero position taken with the lance resting on the furnace-roof access-port cover was the same both at the beginning of the day and after the measurements. This is significant observation as it is believed that the furnace roof can itself rise and fall relative to the tap-holes by as much

as 20 mm. This rise and fall appears to coincide with changes in furnace power and was therefore expected to remain steady during constant power operation.

Determined matte levels – Day 2

Likewise, matte measurements were consistent and reliable on day 2. The relevant measurements are displayed in Table II. The precision of these dips had improved to ± 5 mm. A single, clean matte tap was made at 09h42, between dips 15 and 16. The reduction in level is consistent with the 18 mm furnace depth drained during a standard 8-tonne ladle tap. During the two-hour pause between dips 16 and 17, at least one tap was made. Then at 12h56 a ladle was tapped to overfilling. It is believed that up to 12 tonnes of matte were tapped at the time. This coincides with the level reduction detected by the Agellis system.

Table II: Matte-level measurements for day 2

#	Comments Day 2	Day (YY-MM-DD)	Time (HH:MM)	Zero position (mm)	Virtual bottom (mm)	Matte entry (mm)	Matte level (mm)
15A	Successful dip	2010-10-13	09:05	1300	6760	6428	332
15B	Successful dip	2010-10-13	09:13	1300	6760	6439	321
16A	Successful dip	2010-10-13	09:46	1300	6760	6459	301
16B	Successful dip	2010-10-13	09:48	1300	6760	6456	304
17A	Successful dip	2010-10-13	12:14	1300	6760	6477	283
17B	Successful dip	2010-10-13	12:20	1300	6760	6477	283
18A	Successful dip	2010-10-13	13:09	1300	6760	6500	260
18B	Successful dip	2010-10-13	13:22	1300	6760	6506	254

Determined matte levels – Day 3

On the third day, measurements continued with good results. The first two pairs of measurements were taken during a power-off period to ensure that this did not affect the measured levels. The results were consistent with the sounding bars, and the system was able once again to detect matte-tapping operations. We determined that the power switched off did not adversely affect the ELP system.

Table III: Matte-level measurements for day 3

#	Comments Day 3	Day (YY-MM-DD)	Time (HH:MM)	Zero position (mm)	Virtual bottom (mm)	Matte entry (mm)	Matte level (mm)
19A	Successful dip	2010-10-14	08:32	1300	6760	6482	278
19B	Successful dip	2010-10-14	08:38	1300	6760	6489	271
20A	Successful dip	2010-10-14	08:56	1300	6760	6478	282
20B	Successful dip	2010-10-14	09:00	1300	6760	6484	276
21	Successful dip	2010-10-14	11:35	1300	6760	6498	262
22	Successful dip	2010-10-14	11:54	1300	6760	6527	233

As before, the precision of these dips was found to be ± 5 mm. Matte was tapped between dips 20 and 21 at 10h30, and again between dips 21 and 22 at 11h44.

This is clearly reflected in the Agellis matte-level measurements. A graphical summary of the matte-level measurements appears in Figure 11. It is clear that the readings remained consistent with plant operation over time. It is also worth noting that while the Agellis system consistently detected matte levels, the sounding bar results were often difficult if not impossible to interpret by our operators.

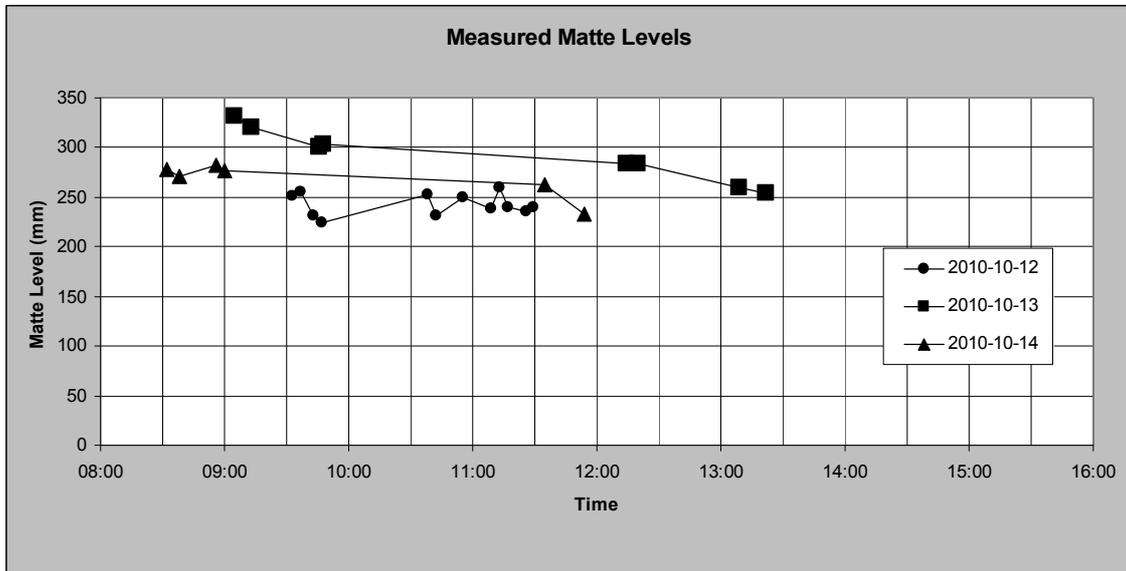


Figure 11: Summary of matte-level measurements

PRACTICAL DIFFICULTIES

As to be expected from trials of a new technology, one encounters some small snags. These were identified and solved during the trial period. Initially, there were problems with reliable winch operations. These were largely due to an ELP lance that was lighter than traditional sounding bars. The automatic load detectors were not triggering correctly and the winch bottom detection cut-off system would often trigger prematurely. Furthermore, the lighter lance caused the winch to un-spool at the bottom position. More seriously, the sounding-bar-oriented winch controls took a long time (more than 10 s) to stop at the bottom of the furnace. The solution was to reduce the winch cable diameter to 6 mm (previously 8 mm) and to adjust the winch load detectors to match the winch mass better. And by adding fixed rotation limits for maximum and minimum winch position we avoided the devices hitting the bottom altogether and the associated thermal exposure.

Another concern was the cumbersome upper lance connection that would make any future changing of lances difficult for our operators. The smelter team suggested that Agellis add a simpler, quick-release connector from the lance top to the sensor cable. This modification made lance switching much easier and less prone to cable damage.

IDENTIFIED LIMITATIONS

The draw-wire version of the EMLI ELP system does have some inherent functional limitations. Interestingly, these limitations all stem solely from the mechanical components of the delivery system. The issues are –

- *Slag cracking*: the freely hanging lance does not have the mass to penetrate thick slag
- *Depth precision*: the draw-wire depth-measurement system is a limiting factor to matte-level precision
- *Additional measurements*:
 - Temperature
 - Metal sampling
 - Slag-level detection
- *Detection of build-up*: the lance does not always hit the bottom of the furnace at the same place. Therefore the measured bottom depths are unreliable
- *Rate of descent*: the lance is positioned with a standard winch and cable. This restricts the descent and ascent to a fixed speed and also an unnecessarily long period of thermal exposure to the sensor.

OVERCOMING LIMITATIONS

In order to evaluate the EMLI-ELP measurement concept quickly and easily, Lonmin's ELP system was installed with a draw-wire- and winch-based delivery system. However, a lance carriage delivery system would address all the limitations identified during the trial.

A lance carriage delivery system solves these difficulties in the following way:

- *Slag cracking*: the lance carriage is powerful enough to crack thick slag. If necessary an alternate cracking lance can be employed to avoid damage to the ELP lance. This would ensure that measurements are not stopped.
- *Depth precision*: lance carriages use chain drives or similar high-precision motive delivery of the lance. This provides considerably higher precision.
- *Additional measurements*: a lance carriage provides many additional possibilities and options for measurements of temperature, slag level and metal sampling. Multiple lances may be mounted on the same carriage.
- *Detection of build-up*: since a carriage-delivered lance is not free to move, it will reliably hit the same point on the bottom of the furnace each time. This makes possible the detection of exact changes in bottom build-up.
- *Rate of descent*: A lance carriage can be programmed for variable descent and ascent speeds to ensure optimized and safe slag cracking while still enabling dynamic speeds in the vicinity of the target furnace areas. This can help to increase measurement resolution while minimizing thermal exposure to the ELP sensor.

DIRECT BENEFITS OF THE ELP SYSTEM

By installing the Agellis ELP system, we have achieved the following benefits:

- An immediate, improved uniformity in level results, eliminating operator interpretation errors
- Better control of levels and therefore tapping decision making
- Better prevention control of slag carryover to tapping ladle
- An improved understanding of the melting process with respect to matte production over time
- Increased safety by preventing matte levels from reaching the water-cooled areas of the furnace
- More accurate measurements that are not affected by bottom build-up. This is possible as we are now able to measure the distance from furnace roof to matte directly and are thereby no longer dependent on the condition of the furnace bottom.

CURRENT ELP STATUS

The Agellis EMLI-ELP system is currently in use at Lonmin's smelter facility. It is being operated as a high-precision comparison tool and provides furnace data complementing the standard sounding-bar procedure and furnace prediction modelling software. Our goal is to increase the frequency of the ELP dipping tool and to automate fully the matte-level-analysis algorithm on Lonmin's process-control systems. Once this is complete, ELP dipping will be integrated into the daily tasks of our sounding-bar operators.

CONCLUSIONS

The measurements attained during the trial period were consistent, reliable and accurate to within reasonable limits. The matte-detection signal itself was very strong and clean, surpassing expectations. The system is currently integrated with our PLC via the 4–20-mA communication lines in place. These lines supply the critical sensor and draw-wire signals required to determine matte levels, using the 1% rule. The smelter team is aware that the system can communicate many more parameters, including internal system temperatures and other system-health-monitoring signals. The system can even be upgraded to perform the matte-level determination in the *control unit* itself, although we felt this was unnecessary for our purposes.

By installing the Agellis ELP system, the smelter team has derived many practical benefits; specifically, a method for ascertaining the level of matte in our furnace, one that is independent of the sounding bar and not affected by changes in the furnace bottom. Naturally, more work is needed to upgrade and integrate the ELP system with our own process-control systems; but even now the smelter team can conduct reliable matte-level determinations to back up the efforts of our sounding-bar operators.

ACKNOWLEDGMENTS

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Trevor joined Mintek in 1988 after completing a National Diploma in Chemical Engineering at Peninsula Technikon. He completed a National Higher Diploma at Vaal Triangle Technikon in 1991. He worked in the Pyrometallurgy Division at Mintek from 1988 to 1994 and from 1997 to 2007. He was involved mostly in high-temperature processes, particularly those of ferro-alloys and precious metals. During 1994-1997 he worked at Richards Bay Minerals as a plant metallurgist at the iron injection and molten product transfer plants. During his time at RBM he was also employed as Senior Production Supervisor, Iron Injection and Molten Product Transfer Plants. Trevor is currently employed at the Smelter Hot Section at Lonmin. His duties revolve around process optimization, monitoring furnace integrity, and maximizing smelting output.
