# Tap-hole monitoring technologies

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This paper provides a progress update on three tapblock monitoring technologies that Hatch has been developing with our clients for non-ferrous smelting furnaces.

The Tapblock Diagnostic System (TDS) is an advanced on-line monitoring system that uses temperature data along with embedded thermal model results to evaluate the condition of a tapblock over its campaign life. Hatch recently installed a second Tapblock Diagnostic System, some details of which are provided in this paper.

The Tap-hole Acoustic Monitoring (TAM) system is installed on water-cooled copper tapblocks and uses the noise from the tapping channel to provide a qualitative indication of wear and deterioration of the tapping channel refractory. In addition, TAM can be used to monitor drilling and lancing performance, and potentially could also be used in the future as a guide for automatic drilling and lancing systems (Sadri *et al.*, 2008).

The third technology is the use of fibre optic sensors to measure temperature on the hot face and in the tapping channel of a tapblock. Fibre optic technology allows installation of numerous sensors in key locations where they are very sensitive to tapblock condition and also provide more extensive spatial coverage than is possible with traditional instruments. This paper provides an update on our efforts to address issues with premature failure of the sensor cables due to corrosion, and also converting the vast amount of data from the sensor cable into information that can be used by furnace operators.

## Introduction

Electric arc smelting furnaces utilize highly intensive processes to smelt the charge and separate the metal content. The challenge with the furnace is to keep the molten material and the slag safely contained inside the crucible, which requires plant staff to monitor and maintain the furnace and associated equipment very carefully. The tapblock is the fastest wearing component of the furnace, and as a result requires a maintenance programme. The aim of the technologies described in this paper is to obtain reliable measurements from the harsh environment inside and around the furnace, and to interpret the measurement data so that the plant staff can make informed decisions early enough to maintain safe and reliable operation of tapblocks.

Hatch is a major supplier to the platinum and nickel industries where a tapblock consists of a 1 $m^3$ block of copper lined with approximately 300 mm of ceramic refractory. The copper block is water cooled internally with an intricate pattern of channels. During tapping, the flow of molten metal or slag through the tapblock gradually erodes the refractory and if the refractory is not maintained correctly, an uncontrolled tap can result. This is obviously very dangerous for operators. Equipment may also be damaged during an uncontrolled tap, resulting in extremely costly repairs and lengthy maintenance downtime. Hence, the tapblock must be maintained regularly. The plant personnel usually adopt a conservative approach and maintain the tapblock frequently to reduce the risks of an uncontrolled tap. Better monitoring enables a condition-based maintenance plan, thereby enabling the tapblock to be maintained in optimum condition, keeping production losses to a minimum.

The development of the tapblock monitoring systems described in this paper is driven by the desire for a real-time monitoring system.

## Tap-hole Acoustic Monitoring system

### *Background*

An acoustic monitoring system for assessing the condition of the refractory lining in a tapblock was developed in close cooperation with Kennecott Utah Copper (KUC). The Tap-hole Acoustic Monitoring system, or TAM, makes use of acoustic emission events from the tapblock to evaluate the condition of the refractory lining and copper coolers within the block. The prototype TAM system was installed on two KUC tapblocks for continuous monitoring. A detailed description of TAM is given by Gebski *et al.*, (2013).

***Development and installation***

The TAM software processes and displays data from a set of acoustic emission (AE) sensors installed around the tap-hole, typically on the cooling water pipes. Using these pipes as waveguides implies that the computed location of an AE event is always related to a specific position along the cooling coil. This is converted to a particular location in the nearest brick in the tapping channel. However, technically this is not a 3D source location algorithm – the 3D presentation of the results is added only to simplify the interpretation. A potential enhancement to this design would be the installation of specially designed waveguides to improve the sensitivity of the AE sensors. This would also allow the actual 3D source location algorithm to be used for evaluating the damage in the tapblock. In either case, the AE signal is transferred from the sensors via preamplifiers to the processing unit. An example installation of selected TAM components is shown in Figure 1. The required number and the optimal type of sensors are determined individually for each tap-hole based on its design and through a calibration process. At KUC, four AE sensors were installed on the cooling pipes. The drilling and lancing activities cause acoustic emissions which travel through the refractory and cooling pipes to the sensors.

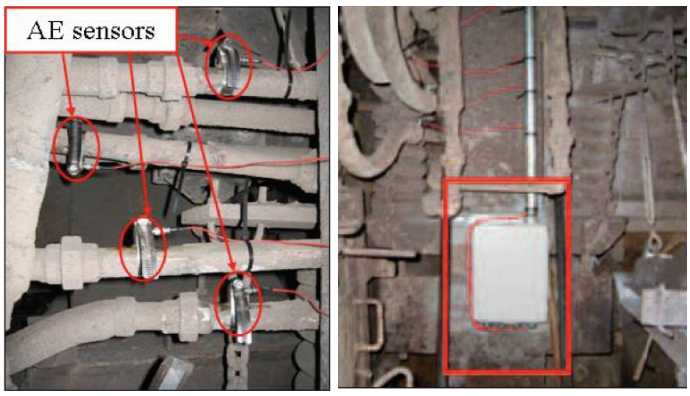


***Figure 1. AE sensors and preamplifiers installed near a tap-hole***

When designing the TAM system it was critical that both the furnace operators and the personnel on the tapping floor be able to respond accordingly to the TAM feedback. The design included a human-machine interface HMI) screen for furnace operators and a light pole near the tapblock for personnel on the tapping floor. Figure 2 shows the main operator screen with a frontal view of a tapblock divided into twelve zones, i.e. four zones on the left, four at the bottom, and zones on the right.

Depending on the difference in arrival time at the four sensors, the source of the AE can be localized to one of the twelve zones. The operator screen gives a qualitative indication of the copper or brick erosion rate in the tapping channel or indicates off-centre lancing or drilling based on the number and intensity of AE events detected in each zone.

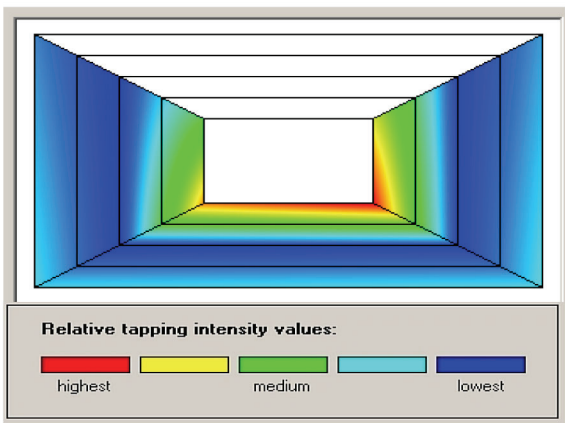


***Figure 2. Brick erosion in the tapping channel (TAM screen capture)***

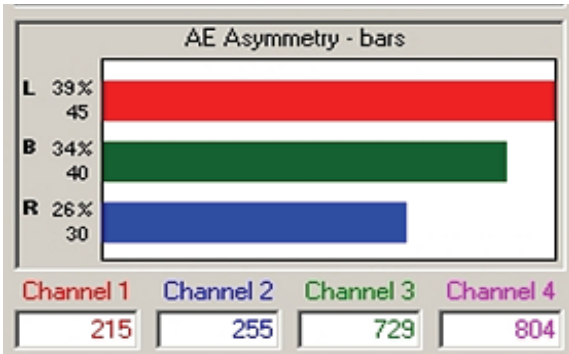


***Figure 3. Orientation of drilling or lancing (skewed to the right (R) – the red bar) as indicated by the increase in AE activities***

The image in Figure 2 shows a higher rate of brick erosion in the bottom right section of the block towards the hot face. This parameter is measured and updated on the screen frequently to show which area of the block is currently most affected, allowing lancing and drilling performance to be displayed in real time.

Optimal drilling should result in a uniform distribution of the AE signals detected in the left, right, and bottom sections of the block. Skewed drilling or lancing is detected by an unequal distribution, as shown in Figure 3, where the drilling and lancing activity is skewed to the right. These results displayed on the screen in the control room and on the tapping floor light pole allow the tapper to take corrective actions and avoid damaging the tapblock. The recorded data is also archived and over the long term it provides trends regarding the tapping practices and the resulting deterioration of the tapblock. This, in turn, helps to improve the maintenance schedule and to develop optimized tapping routines.

### *Case study: off-centre lancing*

Within the first few months of operation, the TAM system performance and reliability was validated by several incidents; one of which is discussed below.

Due to off-centre lancing of a tap-hole, the refractory inserts were severely damaged. Towards the hot face, the hole was drilled approximately 7.6 cm (3 inches) lower than normal and oriented to the right side of the tap-hole. The opening was as close as 2.5 cm (1 inch) to the copper block. The reduction in refractory thickness resulted in less attenuation of the AE signals compared to normal. The locations of the high acoustic intensity zones identified by TAM within the tapping channel are shown in the top part of Figure 4. For comparison, the lower part of Figure 4 shows the AE map during normal operation. Clearly, the off-centre lancing resulted in a cluster of high-intensity AE signals towards the right side of the tapping channel near the hot face. When the refractory inserts were removed, inspection revealed erosion of the bricks in the area identified by TAM. The most severely damaged areas were found on the right and bottom of the tapping channel, as shown in Figure 5.

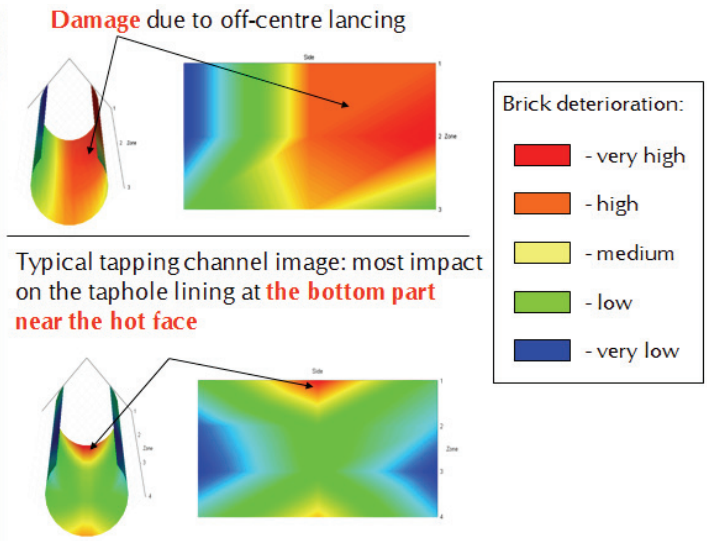


***Figure 4. Brick deterioration measured by TAM. Left side shows the tapping channel and right side shows the developed view of the tapping channel***

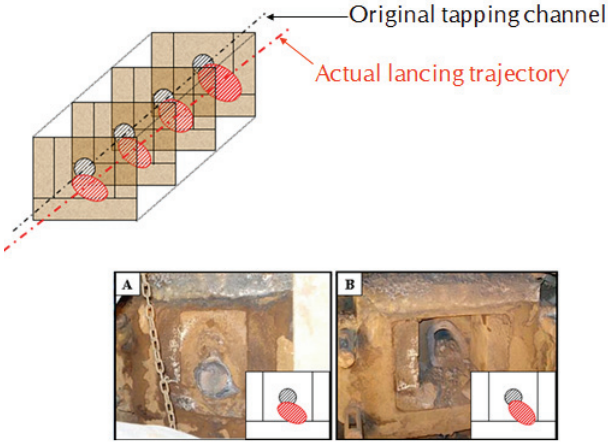


***Figure 5. Actual brick damage in the tapping channel***

### *Summary of acoustic monitoring*

During the initial two years of operation, the TAM system proved its capability to provide real-time monitoring of tap-holes. In summary:

- TAM provides a means to reduce the risk of off-centre drilling and lancing, thus extending the lifespan of a tap-hole
- The sensors can be retrofitted to a tapblock already in service
- Although the TAM system can be used for long-term continuous monitoring of the tap-hole deterioration, it also provides instant indication of faulty lancing and drilling practices
- The acoustic emissions are recorded and analysed throughout the furnace operations to monitor for any events related to a potential tapblock breakdown. These include lancing, drilling, tapping, and the periods when a tapblock is plugged
- TAM may provide feedback for future automatic drilling and lancing systems.

## Fibre optic temperature monitoring for tapblocks

### *Background*

Several years ago, Hatch introduced fibre optic temperature sensing technology to enhance tapblock monitoring (Gerritsen *et. al.*, 2009). This technology, which uses the wavelength of light to measure temperature, was invented decades ago but has more recently found application in industry. The basic principle of operation is that an etched pattern on the core of a fibre optic strand will reflect light at a specific wavelength. The etched pattern changes with temperature such that the wavelength of the reflected light is proportional to the temperature change. Like any temperature sensor, the response to changes in temperature is calibrated to provide absolute temperature measurements.

Prior to the use of fibre optics, the best practice to evaluate tapblock condition was a combination of thermocouples to monitor spot locations in the copper and resistive temperature devices (RTD) and flow meter measurements to monitor the overall heat flux from changes in water temperature. The key benefits of the fibre optic temperature sensors are the small size of the fibre and the ability to install many sensors along a single fibre optic strand. In the case of the tapblock, the fibres are installed across the hot face, on or just below the surface of the copper. Figure 6 shows an example of an installation with two fibre strands (in red) on the copper surface. Sensors are typically spaced at 50–100 mm intervals over the regions of interest. A typical installation will involve the addition of 50 fibre optic sensors per tapblock. In contrast, the yellow tubes show a typical thermowell arrangement – in which case this tapblock can accommodate only eight thermocouples.

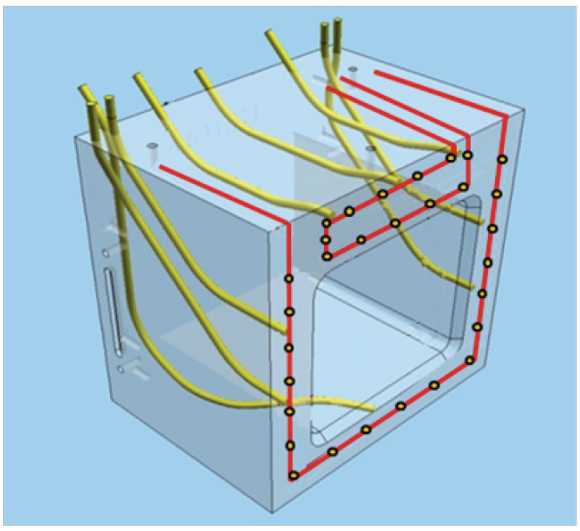

***Figure 6. Tapblock showing location of thermowells and fibre optic cables***

In addition to the benefits of increased spatial coverage, the small diameter of the fibre allows the sensors to be located such that sensitivity and longevity can be optimized. In general, one sees a larger response to changes in refractory thickness the closer the sensors are positioned to the molten bath. However, in order to ensure their survival the sensors need to be located on or inside the copper face to protect them from excessive heat and corrosion.

### *Installation challenges*

In the original installation design in 2009, an alloy tube was used to protect the fibre optic sensor cable. The tube is mounted onto the copper surface and shielded from the bath by refractory. This design works well in furnaces that do not suffer from corrosion, as it provides excellent sensitivity to changes in refractory thickness.

In the installations in South Africa, this design has not worked well due to the high rates of corrosion. Even though the alloy tube was corrosion resistant, the temperature readings became unreliable after a period of approximately six months due to corrosion of the alloy tube. Surprisingly, the fibre cable remained intact even after the protective tube was corroded away.

During the subsequent installation in 2012, several changes were made to the design to increase its corrosion resistance. The objective was to increase the life of the sensor and keep it on the surface of the copper to ensure the sensitivity to changes in refractory were maintained. To do this, the corrosion allowance was substantially increased by installing the fibre optic cable in a larger cross-section bar. While the alloy used in the bar design was similar to the tube alloy, the specific grade was further refined based on the corrosion mechanisms that exist at the copper-refractory interface.

The bar design lasted substantially longer than the tube design in these furnaces. In most locations it lasted the full year-long campaign. On one of the tapblocks, in the chamfer area (just above the tap-hole on the hot face) the sensor was compromised towards the end of the campaign. In terms of longevity, the installation was more successful. However, there were some issues with consistency of measurements between different tapblocks, which made translating the temperature into refractory condition difficult.

In 2013, two new designs were implemented. The first design is a modified sensor bar where pockets are machined into the surface of the tapblock to slightly recess the sensor bar. The pocket and sensor bar surfaces are also machined to a high tolerance to ensure that there is excellent thermal contact between them. Better contact and cooling of the sensor bar will improve both measurement consistency and corrosion resistance. A corrosion resistant coating was also applied to the sensor bar. The thermal conductivity of the coating is equivalent to the thermal conductivity of the castable refractory, and so it is thermally indistinguishable.

The second design implemented in 2013 involves casting the protective tubes into the copper block. This has clear advantages with respect to protecting the tube from corrosion. Consulting with the designers of the tapblock was crucial to ensure the heat removal capability of the tapblock was not compromised by the addition of the sensor tube. Another important consideration is positioning the tubes to maximize sensitivity to changes occurring on the hot face. This involves a trade-off to keep the protective tubes as far as possible from the water pipes, but still embedded deep enough to avoid the risk of exposing the tube through the hot face during the casting process or subsequent corrosion.

After the tapblock was fabricated, ultrasonic testing (see Sadri *et al.*, 2009) was carried out to confirm the position of sensor tube relative to the water pipes and hot face of the tapblock. This was essential to confirm that tubes had not shifted during the casting process, for the following reasons:

- The tubes must be a minimum distance from the hot face
- The location of the tubes relative to the copper hot face surface and the water pipes greatly affects the ability to determine refractory condition from the temperature reading.

Both of these systems were installed in June 2013 and are currently being evaluated. The planned two-year campaign is in a relatively early stage at the time of writing, but both designs are performing well.

***Approach to relating measurements to tapblock condition***

Once installed, the sensors greatly increase the monitoring capability on the tapblock. However, the full value of these measurements cannot be realized unless one can interpret the data. For example, it is difficult to understand the significance of a 10°C change unless it can be put into context and related to the refractory wear on the tapblock.

Experience is needed to establish the relationship between temperature and condition. The challenge with this approach is that the hot face of the tapblock can be fully inspected only when the tapblock is removed from the furnace, typically after one to two years. The slow rate of feedback limits the value of this approach. The approach that has been followed is to use thermal modelling to establish a matrix of conditions and corresponding temperatures in order to be able to predict the condition of the tapblock. Brick repairs in the tapping channel, which take place every several weeks, allow more frequent feedback, enabling operators to gain confidence with using the thermal modelling approach.

A basic cross-section through a tapblock is shown in Figure 7. Using knowledge of the properties of the materials and the temperature of the bath and water, it is possible to compute the expected measured temperature (TFO) using heat transfer relationships.

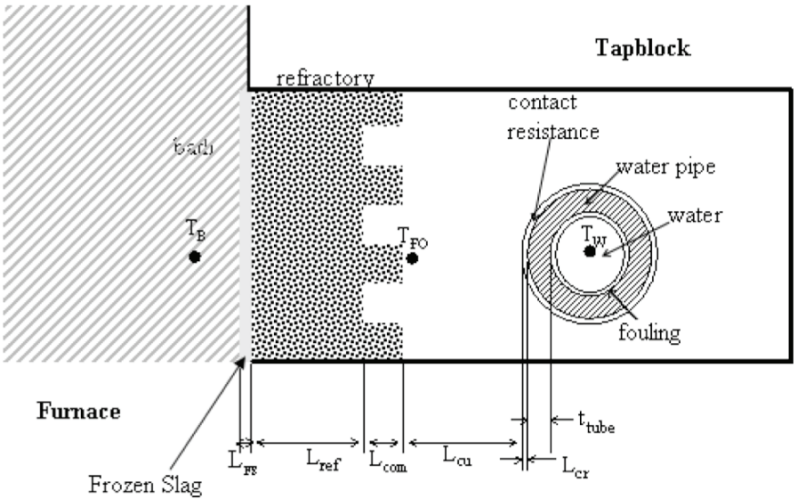


***Figure 7. Heat transfer schematic***

The tapblock condition can be evaluated by characterizing the refractory profile over the life of the tapblock (from new to fully worn) and using the model to calculate the associated temperatures at each location. The geometry of the tapblock necessitates the use of three-dimensional models. Transient analysis is also important for understanding how the temperatures respond temporally to tapping events. Computational fluid dynamic (CFD) software, such as ANSYS Fluent, can be used to develop the models and simulate the heat transfer throughout the block.

***Thermal modelling***

The challenge, as is the case with any model, is ensuring it provides a good match to the process and is therefore able to provide realistic predictions of condition. Preparing the model is relatively straightforward using the detailed CAD designs of the equipment and the material properties. Determining the boundary conditions for the model is a more challenging task, since in many cases these parameters are not measurable and can change over the life of the tapblock. These parameters must either be established from plant data (such as cooling water temperature, bath temperature, etc.)

or from the experience of experts in the field (such as the refractory wear profiles). By establishing the relative significance of these parameters for the accuracy of predictions through a sensitivity analysis, it is possible to characterize the impact of the uncertainty in each parameter.

A sensitivity analysis was conducted using the thermal model by changing model parameters within their expected range of variation. For example, bath temperature would not be expected to vary more than ±150°C around the target temperature. From this sensitivity analysis, the most significant factors impacting the temperature measured at the copper-refractory interface, in order of impact on the measured temperature are:

- Refractory thickness
- Tapblock thermal resistance
- Thermal conductivity of refractory
- Cooling water supply temperature.

Other variables, such as the bath temperature and the bath convection coefficient, were shown to have a fairly limited influence on the measured temperature. Refractory thickness is the variable most interest in when trying to establish the condition of the tapblock. It is a fortunate result of the sensitivity analysis that the refractory thickness has the greatest impact on the measured temperature. Another fortunate result is that the impact of the uncertainty, associated with all these parameters, decreases as the thickness of refractory decreases. Consequently, when there is little refractory remaining, the measured temperature is almost completely governed by the refractory thickness. This makes the estimate of refractory thickness from temperature data most accurate when the refractory is thin and the results are needed the most.

The effective thermal resistance of the tapblock is defined as the measured thermal resistance between the water and the sensor. It is our experience that the effective thermal resistance tends to be higher than the theoretical value (as determined using theoretical values for the thermal conductivity of the relevant components) and can vary due to location. Most likely this is due to bonding resistance between the water pipes and copper and any scale build-up in the cooling pipes. Thermal modelling studies have shown that ignoring this effect can result in significant errors in the prediction of remaining refractory thickness from temperature data. The effective tapblock thermal resistance is unique for each tapblock and sensor location and ideally should be measured. The bump test described in the section on the Tapblock Diagnostic System is a method that has been developed to measure the tapblock thermal resistance in the field.

The thermal conductivity of refractory material is known to vary around the manufacturer's specifications. An error in this value will impact the accuracy of the refractory thickness estimate by 1% for every 1% error in the thermal conductivity. Ideally, the thermal conductivity of refractory installed in key locations should be established to within several per cent. To fully understand the thermal conductivity of the refractory, one needs to determine the degree of impregnation from the metal/matte and how this changes with time. Measuring the degree of impregnation at every repair opportunity would enable a better understanding of the change in conductivity as a function of throughput.

The inlet cooling water temperature also has a significant impact on the temperature measured by the sensors. For every 1°C change in water temperature most sensors will experience a 1°C change. This can greatly bias estimates of refractory thickness because the cooling water temperature can vary by several degrees over a single day, and even more over the different seasons of the year. Fortunately, these variations can be eliminated from the fibre optic temperature measurements by measuring the inlet water temperature and subtracting the variations.

***Evaluation of temperature measurements***

Figure 8 shows the measured temperature response of one of the fibre optic sensors to a sequence of tapping events. This sensor is physically located on the copper hot face above the tapping channel in the centre of the tapblock. The vertical black lines show the tapping events. The green, yellow, and red lines show the expected steady-state tapping temperatures for that sensor for a new, half worn, and fully worn refractory conditions.

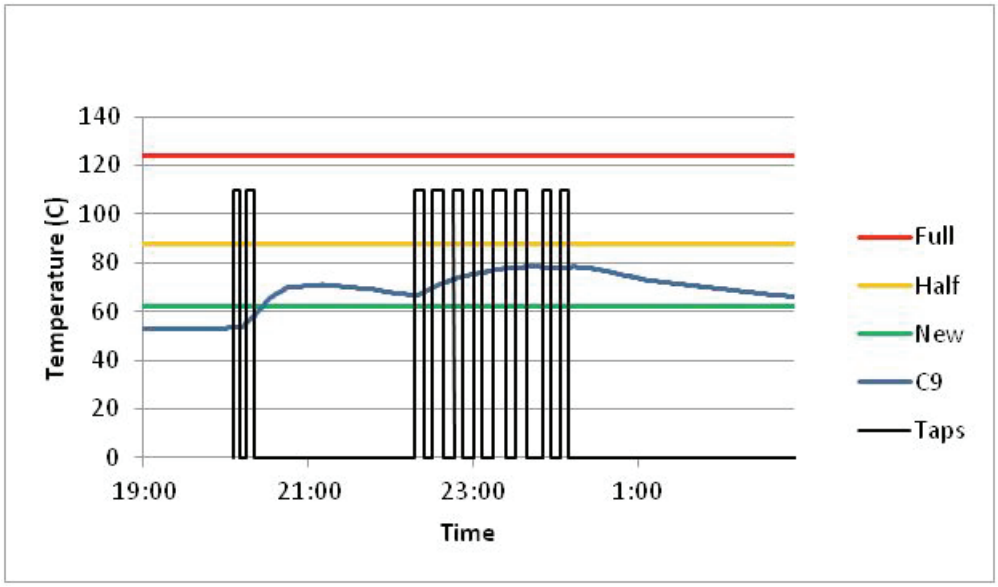


***Figure 8. Thermal response of sensors to a tapping event***

Several interesting observations about the measured temperature data in Figure 8 are noted below:

- Installation of the sensor at the copper-refractory interface provides very good sensitivity to changes in refractory thickness. The expected temperature at this particular sensor covers a range of over 60°C as the refractory deteriorates from a new to fully worn condition. In contrast, thermocouples imbedded in the copper may increase only 2–3°C for the same change in refractory from new to fully worn state. The increase in sensitivity provided by the surface mounted sensor greatly enhances one's ability to discern a change in the condition of the refractory, and hence confidence in the results
- The delayed response following the start of the tap is consistent with the refractory's low conductivity and the slow absorption of the energy from the molten material. It is also evident that the temperature continues to rise at the copper-refractory interface after tapping ceases as a result of the energy stored in the refractory (see times between 20:00 and 21:00). The transient response of the temperature reading is directly related to the amount of refractory. Work is currently under way to develop a relationship between the transient temperature response and the refractory thickness. It is necessary to have an understanding of this relationship for smelting operations that tap occasionally and where the tapblock never reaches thermal equilibrium, as shown following the first two taps in Figure 8
- Shortly after 23:00, it can be observed that with subsequent tapping there is no associated increase in the temperature above 80°C. This is defined as the steady-state condition for continuous tapping, where the heat load from exposure to the molten material is balanced by the cooling water. In this state, it is possible to evaluate the refractory condition on a consistent basis each time. Based on the wear reference lines (new, half worn, and fully worn) determined from the thermal model, it is expected that the condition of this tapblock is approaching a half-worn condition.

The pre-tapping temperature (about 53°C at 19:00 in Figure 8) of the tapblock depends on a number of parameters that cannot be measured, and which are related to variables such as the time since the last tap and clay plug position. The consequence is that condition assessment during the non-tapping period is very challenging. It has been found that the most reliable time to evaluate the condition of the tapblock is during a period of continuous tapping (see period 23:30 to 00:00 in Figure 8). In this state there are fewer unknown parameters that confound the assessment.

Through both simulations and evaluation of plant data from our fibre optic temperature sensors, it has been shown that the tapblock may reach a steady-state temperature corresponding to the refractory condition. In reality, a steady-state temperature is approached by tapping for a sufficient duration, or tapping repeatedly in quick succession as shown around time 23:00 in Figure 8. Through thermal modelling simulations it has been established that this 'steady-state' temperature achieved by tapping in quick succession is within 2–3°C of the temperature reached when continuously tapping. Considering the 60°C temperature ranges from new to worn, this deviation from the temperature reached during continuous tapping is negligible.

***Summary of fibre optic sensors***

In summary:

- A large number of measurements on a small fibre cable allows good spatial resolution to be obtained as well as temperature readings in locations where it is not possible to install thermocouples
- Thermal modelling is necessary to place the measured values into context and understand the condition of the refractory
- Evaluation of the temperatures at a steady-state condition approaching continuous tapping provides a consistent basis on which to evaluate refractory condition
- Work is ongoing to relate the transient temperature reading from a single tap to refractory thickness for plants where a steady-state tapping temperature is not achieved.

## Tapblock Diagnostic System

***Background***

The Tapblock Diagnostic System (TDS) is an advanced real-time monitoring system that continuously monitors the tapblock throughout its life and accumulates probable wear events to assess the remaining life of the tapblock (Gunnewiek *et al*., 2008; Gerritsen and Gunnewiek, 2011). The main purpose of the diagnostic system is to help the furnace operators safely manage the operation and maintenance of furnace tapblocks. The TDS was first developed in 2003 for Teck Cominco and Lonmin Platinum prior to the fibre optic temperature system, and uses the operating data such as tapblock thermocouple measurements, cooling water temperatures, and flow rates to perform the diagnostic calculations and evaluate the residual integrity of the tapblock. Key benefits of this system include the ability to provide early warnings of refractory wear to improve safety and maintenance planning.

Since the diagnostic system uses temperature measurements from the thermocouples that are embedded in the tapblock, it is important to verify that the temperature measurements are sensitive to the changes in refractory conditions. Otherwise, the diagnostic system could be ineffective in assessing the tapblock condition and may require more instrumentation closer to the refractory to provide a reliable assessment. In such a case, fibre optic temperature sensors can provide a large number of temperature measurements on the tapblock, as discussed previously, and the diagnostic system can analyse those measurements to assess the condition of the tapblock.

Currently the diagnostic system is operating at two sites, namely (i) Teck Cominco, Canada, installed in 2003, and (ii) Portovesme Srl, Italy, installed in 2013. Both plants operate a Kivcet furnace with four tapblocks and the diagnostic system monitors all the tapblocks simultaneously. Several changes have been made to the diagnostic system since the first installation. One of the main changes is the development of a new bump test procedure that can now be performed at any facility to estimate the tapblock thermal resistance. An update on the new bump test procedure and test results are discussed in the following sections. A more general description of the TDS can be found in Gunnewiek *et al*., 2008.

***Bump test procedure***

Tapblock thermal resistance is the overall thermal resistance between the thermocouple and the cooling water, which includes the copper block resistance, bonding resistance between the copper block and water pipe, and the cooling pipe resistance together with the resistance of any scale build-up that may be present in the water pipes. It is important to measure the tapblock thermal resistance in order to obtain an accurate estimate of refractory thickness from temperature measurements.

A bump test is a field trial that can be performed on a tapblock to measure the thermal resistance. The bump test is a procedure that uses the cooling water to temporarily lower the tapblock temperature so that the response of the thermocouples can be analysed to estimate the block's thermal resistance. The response of thermocouples to an induced change in the tapblock temperature is typically characterized by a first-order decay function, and the dynamics of this response vary with block thermal resistance. For example, a higher tapblock thermal resistance results in slow thermocouple response and a lower tapblock thermal resistance produces a faster response. Consequently, the thermocouple data collected during a bump test can be compared to thermal model simulations to estimate the tapblock thermal resistance.

In the Teck Cominco installation, a bump test was performed by abruptly lowering the inlet cooling water temperature. This procedure has produced good results for several years; however, it is difficult to decrease the inlet cooling water temperature for a bump test without access to a source of cold water, which was available at Teck Cominco.

As a result, a new bump test procedure was designed that instead manipulates the cooling water flow rates to cause an abrupt decrease in tapblock temperature. A graphical representation of the procedure and the expected response is shown in Figure 9. The test starts by first reducing the cooling water flow rate to allow the temperature of the tapblock

to increase. Once a sufficient temperature rise is obtained, the bump test is initiated by abruptly increasing the cooling water flow back to the normal flow rate so that the tapblock temperature decreases. The actual thermocouple measurements are then analysed to estimate the tapblock thermal resistance.

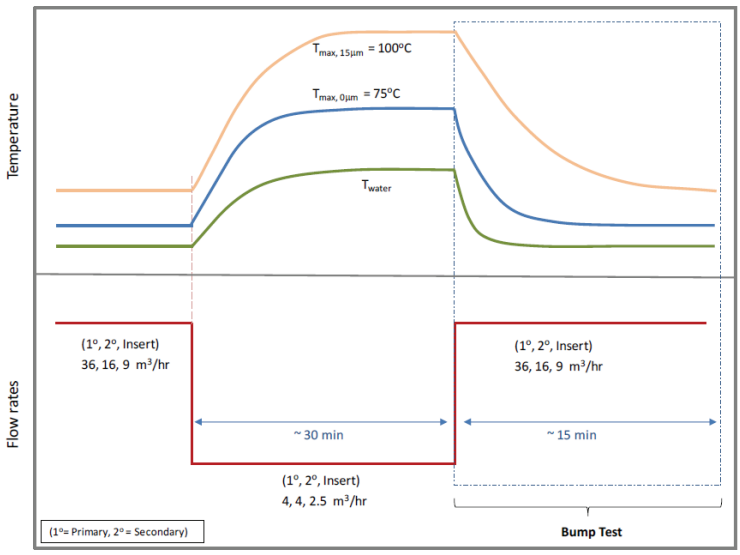


***Figure 9. Graphical representation of the new bump test procedure***

This procedure can be easily performed at any location once the bump test flow rates are appropriately selected to induce the required change in the block temperature. Thermal model simulations are used to establish the flow rates and duration of the test that achieve a balance between providing sufficient change in tapblock temperature to identify the thermal resistance and maintaining tapblock temperatures within acceptable limits. Furthermore, thermal modelling is also used to determine the transient response of the tapblock to a sudden increase in water flow rate for different tapblock thermal resistances. Such simulation results are used to calibrate the bump test models (essentially first-order transfer functions) that are used together with a field 'bump test' data to estimate the block thermal resistance at each thermocouple location.

### *Results and discussion*

A bump test was recently performed at a client facility on one of the tapblocks using the new procedure. During the bump test, as expected, the thermocouple temperatures increased upon lowering the flow rates, reached a steady state, and finally decreased following a first-order response exactly as shown in Figure 10.

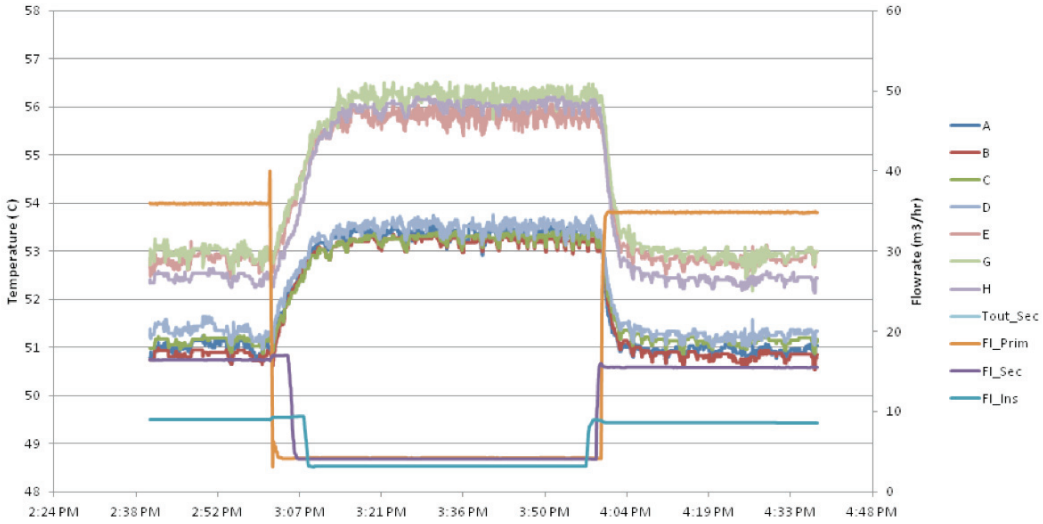


***Figure 10. Field bump test trends***

Figure 11 shows the normalized thermocouple data collected during the cooling portion of the bump test overlaid on the simulation data. The simulation curves are obtained at different block thermal resistances represented by 0, 10, 20, 30, and 40 µm gaps in the bonding between the copper block and water pipe. This range of gaps is taken as a generic way to represent any factor affecting the heat transfer through the copper block to the water pipe. Generally there is no physical gap at the boundary between the copper block and cooling water pipe. A 0 µm gap (i.e. no gap) is perfect thermal bonding and results in the fastest thermocouple response, whereas a 40 µm gap results in a slower thermocouple response as the gap impedes the heat flow from the copper casting into the cooling water. Although this range of block resistance does not represent a problem with the tapblock cooling, the range of values has a significant impact on the interpretation of the temperature readings.

The sample field data shown in Figure 11 clearly indicates that the block thermal resistance is in between 0 µm and 10 µm, and the diagnostic system has precisely calculated the values to be 4 µm. Similar analysis at different thermocouple locations indicated the tapblock thermal resistance is between 2 and 6 µm. These values are in the same range as those obtained for the Teck Cominco tapblocks using the previous bump test procedure, thus providing confidence in the new procedure.

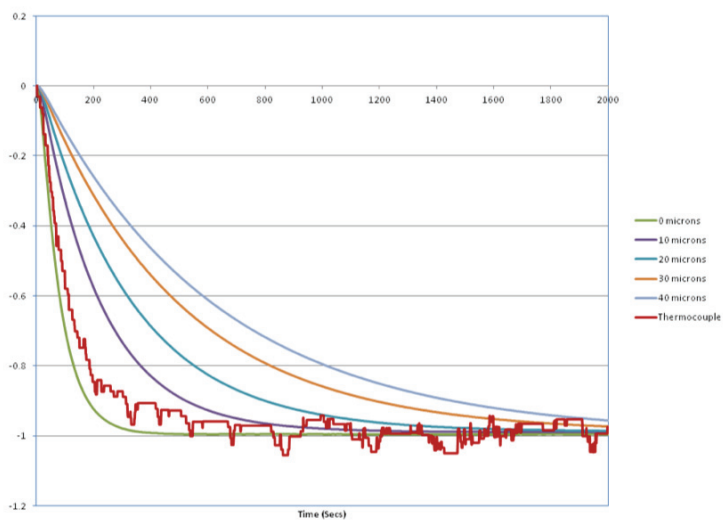


***Figure 11. Block thermal resistance estimation***

Once calibrated with the tapblock thermal resistance, the diagnostic system estimates the tapblock health during subsequent taps. It was found that after about six months of operation and nearly 300 taps, the health of the tapblock was about 87%. This indicates that the tapblock is still in good condition and can safely be used for an extended period of time.

### *Details of the recent installation*

The TDS recently installed at Portovesme Srl was developed in National Instruments control software 'LabVIEW' to simultaneously monitor four tapblocks. The LabVIEW-based system was configured to retrieve the operating data from two Siemens S7 programmable logic controllers (PLCs) via OPC, and write important information obtained from diagnostic calculations (e.g. tapblock health) to a second PLC so that the operators can access the data from anywhere in the plant through their PI historian. So far, the operation of the LabVIEW-based diagnostic system has been stable without any reported issues.

In general, the diagnostic system must be designed to present the results in a meaningful way to highlight significant events, and the human-machine interface (HMI) must quickly point out key conditions that require operator attention and provide a process engineer with insight into particular events of interest with a first-pass analysis. Figure 12 shows a sample operator display for the TDS screen with easy-to-interpret colour indicators (red/yellow/grey) that are used to alert operators to warnings ranging from instrument failure to tapblock degradation. The HMI also permits further investigation into warnings as required by using the sub-screens for each tapblock.

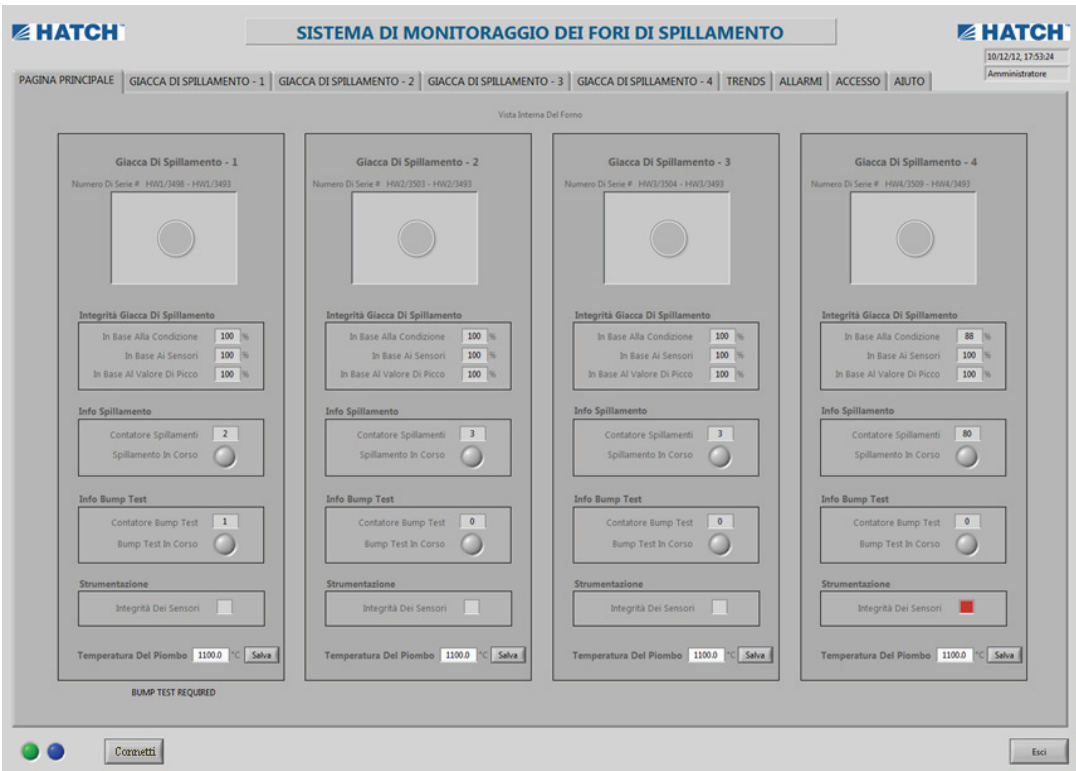


*Figure 12. Overview screen of the TDS at Portovesme Srl*

### *Summary of the Tapblock Diagnostic System*

- It is important to know the tapblock thermal resistance in order to accurately evaluate the condition of the tapblock
- The new bump test procedure was recently tested at a client facility to measure the tapblock thermal resistance and the estimated thermal resistances appeared to be reasonable and in the expected range
- The new bump test based on altering cooling water flow rate can be used at many more operating plants than the previous test, which required a source of cold water.

## Conclusions

Hatch remains committed to the continual improvement of furnace technologies. The Tap-hole Acoustic Monitoring system provides tapping personnel at smelters with on-line and real-time information on the tap-hole condition and can assist with tapping practices. As a result, TAM has strong potential for becoming an integral component of future automated tapping systems that are of interest to many furnace operators.

The new fibre optic temperature measurement technique provides the capability to monitor tap blocks accurately and with an increased number of measurements. The vast amount of data provided by this system is difficult for plant operational staff to interpret manually, and so the computer-based Tapblock Diagnostic System has been developed to assist with the data analysis and prediction of the health of the tapblock.

The Tapblock Diagnostic System has been successfully implemented in two plants. The system has made use of a new bump test technique to verify the thermal resistance of a tapblock. The field results have provided confidence in the new bump test procedure, and this approach can be used at any facility to measure the tapblock thermal resistance.

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