Accurate measurement of furnace heel and transferred weight

A new technology, known as BatchPilot, has been developed which works on the principle of sensing changes in the hydraulic pressure in the furnace main cylinder together with the changes in position of the furnace to accurately measure molten metal heel and transferred weight. A reduction in yield loss of 0.38% was achieved together with an improvement in the 'right first time' charge analyses

By John H Courtenay*

BatchPilot has been applied industrially at Corus Aluminium's Duffel works in Belgium, on a 50t tilting holding furnace since March 2004 with excellent results with respect to accuracy. The objective at Corus was to improve yield through a reduction in the number of over length casts. More recently, it has also been installed on a furnace at Talum (Slovenia).

In the production of aluminium semi finished shapes in the casthouse, difficulties arise with the accurate measurement of the weight of molten metal in the furnace – either in the form of a heel left after completion of a cast, or the amount of molten aluminium transferred into the furnace, in the case of a holding furnace where transfers are necessary from a melting furnace. Weight is generally estimated visually and an accuracy of <2t cannot normally be achieved, leading to substantial possible errors. In the case of estimating the weight of heel, errors make it difficult to achieve 'right first time' when changing alloys resulting in a second or third alloy, composition adjustment step being required. This results in a significant loss of productive furnace time with each step adding a further 30-60 minutes to the batch cycle.

Where transfers are made from a melting furnace to a holding furnace again the amount transferred is estimated visually. The consequence of transferring too little, due either to overestimating the residual heel weight or overestimating the amount transferred, is to cast the ingots short which, in extreme cases, results in the whole cast being scrapped with a significant loss of yield and increased costs for remelting. Because of the undesirability of casting short, casthouses generally build in some safety margin in the batching calculations and also in the estimating process, with the consequence that there is a built-in bias to casting long giving rise to a systematic yield loss.

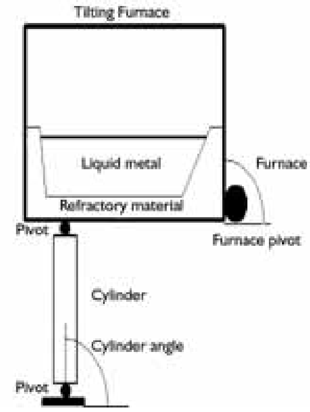
To overcome these difficulties various systems have been proposed including measurement by using a radiation beam such as laser or radar, or the use of load cells(1). Radiation beam techniques have generally failed to achieve reliable results because of the presence of varying quantities of dross on the surface of the molten aluminium making accurate determination of level impossible. Load cells cannot be realistically retro-fitted but have been supplied with furnaces when initially installed; however, subsequent difficulties with maintenance often result in their becoming damaged leading to their subsequent abandonment.

The next section describes the technology and section 3 describes results and subsequent modifications and improvements made in the system over one year's operation in production at Corus Duffel, together with a summary of results achieved at a second plant in Europe where the system was recently installed for Talum.

A new system, *BatchPilot* has been developed(2) which operates on the principle of detecting changes in the furnace cylinder hydraulic pressure and angle in tilting furnaces.

BASIC PHYSICS OF TILTING FURNACES

Fig 1 presents a schematic view of a typical tilting furnace. In operation, the furnace is supported by its pivots and up to two hydraulic cylinders. Therefore, the furnace mass is distributed between the furnace pivots and the cylinder(s). The proportion obviously depends on the location of the centre of gravity of the whole system and can be obtained by straightforward calculations. Due to the geometry of the system, a large furnace angle corresponds to a larger pressure in the cylinder.



1 Schematic of a tilting furnace

At first glance, weighing the liquid metal inside the furnace using the hydraulic pressure in the cylinder seems rather simple. Indeed, knowing the pressure when the furnace is empty, one could establish a correspondence between the pressure variation caused by various amounts of liquid metal to determine the actual metal mass inside the furnace. However, several other parameters must be taken into account in order to obtain an accurate measurement.

First, friction plays a significant role in such a system. Indeed, the overall weight of a tilting furnace can be as high as 500t, imposing a friction force in the various pivots as well as in the cylinder seals. Secondly, leaks, which are always present in hydraulic systems, can make the furnace move slightly over a period of time. Since pressure in the cylinder depends on the furnace position, this can prevent accurate measurements being obtained.

Friction effects can be eliminated by measuring pressure dynamically while forcing the furnace to move, however, the problem then becomes more complex as the centre of gravity of the furnace and that of molten metal move as the furnace angle changes. Furthermore, deposits of dross accumulate on the furnace walls and add several hundred kg over the course of a single day. This creates a 'dead' mass adhering to the furnace walls, that does not move when the furnace is tilted – as opposed to the molten metal – that influences the pressure accordingly.

A series of fundamental experiments(2) were performed to acquire information on the characteristics of the system. The relationships under dynamic conditions between pressure and furnace tilt angle, pressure *versus* time and furnace position *versus* time were studied, allowing a comprehensive model to be developed which could be used to accurately determine the weight of molten metal in the furnace.

In practice, the *BatchPilot* system software is able to characterise any

▶

---

*MQP Ltd, 6 Hallcroft Way, Knowle, Solihull, West Midlands, B93 9EW UK furnace by means of conducting a series of calibration measurements with the furnace completely empty and again when full. Once characterised, the system can be used to determine both heel weights and to continuously monitor the weight of metal transferred into the furnace during transfer.

INSTALLATION AT CORUS DUFFEL

Following presentation of the first results achieved with BatchPilot (presented at the 2003 TMS congress), Corus Aluminium NV agreed to install a system at its Duffel plant for long term evaluation.

There are five casting pits at Duffel casting slabs and billets with a variety of equipment. Metal supply is based on inhouse scrap and bought-in scrap, supplemented with induction-melted light scrap supplied in crucibles from the 'greenmelt' facility. All scrap is pre-weighed and segregated by alloy composition.

Casting line No 7 was chosen for the trials (layout is shown in **Fig 2**).

Corus was then experiencing a yield loss of 0.7% on casting line 7 due to over length ingots and the objective for the trial was to achieve a yield improvement of 0.4%.

(**Fig 2)**, The induction furnace melter (A) had a capacity of 70t and was normally run with a constant heel of 20t to cover the inductors. Transfer of 35-55t takes place over a hydraulically-operated transfer launder (B), connected to the narrow side of the 50t holder (C) and at right angles to the direction of flow to the casting table (D). After leaving the holder, metal passes through an in-line degassing unit (E) and a filter box (F).

Installation of the hydraulic sensor at the base of the one of the furnace's two hydraulic cylinders and the tilt angle sensor on the furnace shell proved to be quite straightforward and was completed within half a day (**Fig 3**).

MODIFICATIONS TO HYDRAULIC SYSTEM

Hydraulic systems, although all the same in principle, vary in detail from plant to plant. In particular, the means of controlling furnace tilt speed can be achieved either with a single continuously-variable valve, or by two or more preset valves, each set with a single flow rate and hence tilting speed.

The latter system was used and it was established during the installation and pre testing procedure that even the 'slow' speed valve was not slow enough to achieve stable readings.

A number of modifications were required:

- The program controlling the plant PLC was altered to tilt at a speed of 1.5 to 2.5mm/second for weight measurements using the *BatchPilot*, where speed is measured from piston displacement. To achieve this, it was necessary to install an additional valve in the hydraulic system to provide a third 'ultra low' speed of 1.7mm/sec.
- Adequate protection was provided for all cables between the position and hydraulic modules the *BatchPilot* and the casting centre PLC.
- A small programme was installed on the plant PLC to respond to *BatchPilot* requirements.
- Modification of security mechanisms to allow filling the furnace when it is slightly tilted (ie supported by the cylinder(s).
- Modification of security mechanisms to allow an uninterrupted 60-second tilting when the furnace is full to prevent overflow of metal.

The *BatchPilot* system has two operational modes; heel weight measurement, and transfer weight measurement.

In heel weight mode, the *BatchPilot* computer requests the casting centre plc to twice raise and lower the furnace, by 100mm over a period of 60 seconds, to make a heel weight measurement. This procedure produces an accurate measurement to within 200kg for heel weights up to 4000kg. This mode is also used to weigh the furnace when full, with an accuracy of 400kg for a 50000kg charge weight.

THE TRANSFER WEIGHT MEASUREMENT

Prior to making a transfer, the furnace must be set up 'off the blocks' by approximately 20mm so that it is constantly and only supported by the hydraulic cylinder pressure. This enables a continuous measurement of the transferred weight to be made with an accuracy of 800kg on a transferred weight up to 50 000kg.

Following modification, the system was calibrated (the results are shown in **Fig 4**). There was good agreement between the *BatchPilot* measurements and the actual weights of metal cast. Particular care had to be taken to accurately weigh all outputs from the furnace, including any dross removed and all metal remaining in launders and filters.

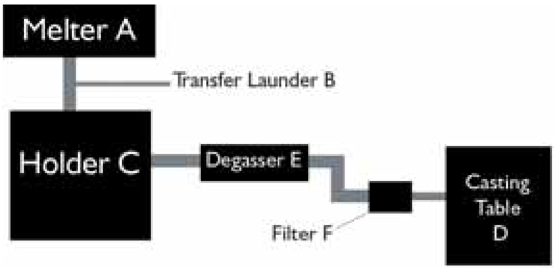
Following calibration, the system was operated in production and measurements with *BatchPilot* compared to calculations of cast weight based on ingot length and theoretical density and cross section. The results from six months of operation are shown in **Fig 5**.

It is important to bear in mind that unlike the calibration test measurements, the data relates to general production and contains all errors including: operator error, incorrect usage sequence, differences in theoretical weight of ingot and actual, incorrect or missed recording of dross removed, unaccounted for metal quantities in launders and filters and *BatchPilot* measuring error.

On balance, agreement between *BatchPilot* measurements and calculated weights was reasonably good, indicating a measuring error of 1200kg compared with the calculated systematic measuring error (based on summation of the heel weight measuring error and transfer weight measurement error) of 800kg. It was considered that certain modifications should be introduced to improve user friendliness and to attempt to eliminate those readings beyond the 800kg range that were occasionally observed.

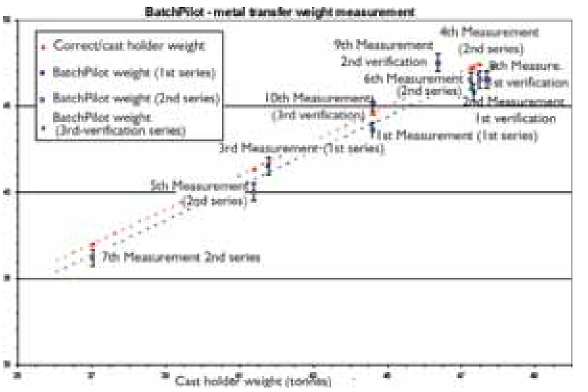
The principal measures introduced related to improvement of the software. Firstly the programme was modified to prevent measurements from being made if the cylinder hydraulic pressure was not stable. This involved introducing a delay of up to 60 seconds before a reading could be made whilst the system waits for the

▶



2 Layout of casting line 7 at Corus Duffel

3 Installation of hydraulic pressure sensor at base of cylinder



4 BatchPilot calibration measurements

hydraulic pressure to reach a stable value. Secondly, a further restriction in the software – to prevent measurements being made out of the correct sequence – was installed. Because the system calculates the weight of any dross build-up after each heel weight measurement, it is important to follow the correct sequence, which is to take a heel measurement followed by a transferred weight measurement. The cycle is then completed by recording the total furnace weight using the 'heel weight' mode.

The system was re-calibrated and all modifications to software implemented in week 34. Data from all production on casting line 7 was collected as before from week 35 to week 41 (**Fig 6**).

STATISTICAL ANALYSIS

The correlation coefficient, *r*, the degree of fit and the value of sigma were determined for the two measuring methods and two operational periods.

Table 1 shows that there was a noticeable improvement in the correlation coefficient after the implementation of modifications and re calibration carried out in week 34. The best figure achieved of 0.89 for the full furnace weight method shows an excellent correlation to the calculated weights and can be considered to be a good result for the system. Also the value for standard deviation, sigma improves markedly to 1647 kg.

Yield loss fell from 0.7% before installing *BatchPilot* to 0.38% after installation, a 45% improvement.

Similarly, regression analysis shows the degree of fit of the linear regression through the data points, indicating that more than 99% of the variation in the *y*-values of the line/model is caused by variation in *x*-values of the model/line. Again the degree of fit is seen to increase in the second period (after amending the system), from 99.5% to 99.8%. (**Figs 5 & 6**).

RIGHT FIRST TIME

To measure any improvement in the analysis of the cast product the number of spectroscopy samples necessary per charge was monitored and a significant reduction in this was observed. At a second *BatchPilot* installation at Talum dd, Kidricevo, a similar check was made and the same trend was observed (as shown in **Table 2**).

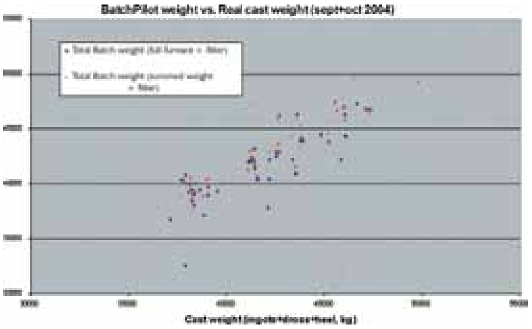
Function	Period 1 prior wk 34 Summed weights	Period 1 prior wk 34 Full furnace	Period 2 post wk 34 Summed weights	Period 2 post wk 34 Full furnace
Correlation coefficient, r	0.75	0.79	0.86	0.89
Degree of fit	0.9957	0.9975	0.9982	0.9985
Sigma, kg	2839	2144	1817	1647

Table 1 Improvement in calibration line fit after modification

	Number of spectroscopy samples Before BatchPilot	Number of spectroscopy samples With BatchPilot
Corus Duffel	1.9	1.6
Talum Kidricevo	1.8	1.3

Table 2 Average number of spectroscopy samples per charge indicating 'right first time' trend

5 BatchPilot weight vs calculated cast weight March - August 04



6 BatchPilot weight vs calculated weight Sept - Oct 2004

CONCLUSION

It can be shown that, under conditions where all inputs and outputs to the furnace are accurately tracked and weighed, while the accuracy of the *BatchPilot* is 400kg or better, depending on which weighing mode is being used, this requires a large amount of effort and the number of charges so closely followed is relatively small.

Rather, the approach adopted was to install the system in continuous operation and collect all data over some nine months production use. All ingot weights were recorded at the scalping station and a correction applied for the actual cast length and other estimations, as are normally recorded by the operators. Ancillary metal weights – such as the weight of metal left in the filters – is collated from the normal plant melt sheets.

This method leads to a number of errors but this is counterbalanced by the large data population generated.

At the time of writing a total of four systems are in daily commercial operation one in North America and three in Europe, with interest having been shown by each of the major aluminium groups. ■

ACKNOWLEDGEMENTS

The author would like to thank the management of Corus Aluminium NV for their support for this project and for giving permission to publish.

REFERENCES

1 Palmi Stefansson, Ole Ingar Vee, Thorsteinn I Sigfusson Molten Aluminium: Recent Advances in Weighing and Transportation Light Metals 1996, Wayne Hale, Ed (Warrendale PA:The Metallurgical Society 1996) pp 635-638

2 Daniel Audet, Luc Parent, Marlene Deveaux, John Courtenay, Aluminium Weighing Measurement in Tilting Furnaces Light Metals 2004, Alton T Tabereaux, Ed (Warrendale PA:The Metallurgical Society 1996) pp 775 - 7788

Interfacing furnaces to management systems

The newly established furnace control company, Axron® is developing what it believes to be the first MES (Manufacturing Execution System) solution for factory or workshop management specially adapted to the metallurgical industry.

The MES provides a genuine interface between the workshop/machine level and the company's management system (ERP or GPAO), and constitutes one of the major development axes for productivity in industry.

Axron Swiss Technology SA, is founded on over 12 years of experience acquired by the Axron technical team at Solo® and Borel®, the two main Swiss industrial furnaces manufacturers.

The company specialises in automation and control of industrial furnaces and equipment for the metallurgy industry. Axron software is used throughout the world on all types of machines and conforms to the prescriptions of the new ISA S95 standards with interfaces in all languages including Asian ones. ■

Sandro Gattigo Tel +41 32 465 10 20 e-mail gattigo@axron.com