Fully automatic refractory maintenance system

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Continuous changes in the economic environment and the increasing competitive pressure require steel producers to introduce innovative measures to reduce costs. The Stahlwerk Bous / Saar GmbH, part of the steel section in GMH-Holding, has over recent years successfully pursued this strategy.
Working with Minteq International GmbH a totally new concept of arc furnace maintenance was introduced. The fully automatic refractory maintenance system was installed in 2003.
The development of an automatic and continuous refractory maintenance system for the arc furnace, tailored of the requirements of modern steel production at Stahlwerk Bous have eliminated the disadvantages inherent in intermittent refractory maintenance. The system consists of a laser scanner, or LaCam™, to measure the residual refractory thickness of the furnace, and of an enhanced version of the robotic MINSCAN™** maintenance system. These components are linked together by means of an interface module called SCANTROL™*, which evaluates the measurement data and controls the robotic maintenance unit, such that the required amount of the correct repair material is automatically applied to the required position. Significant savings have been achieved in terms of reduced maintenance time, reduced repair material usage, reduced brick repairs and reduced energy costs, leading to improved availability of the electric arc furnace and an increase the productivity.*

Keywords: LaCam™*, SCANTROL™*, MINSCAN™ , EAF automatic refractory maintenance system**

INTRODUCTION

Continuous changes in the economic environment and the increasing competitive pressure require steel producers to introduce innovative measures to reduce costs.
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DESCRIPTION OF THE STEEL PLANT

Stahlwerk Bous GmbH now part of Georgsmarienhütte Holding and is located on the banks of the river Saar in the south west of Germany (Fig 1.).
It was built in 1961 and produces more than 260000 t of round, polygonal, rectangular and quadratic, cylindrical, various conical ingots per year for seamless tube mills and forges with diameters ranging from 180 to 1750 mm , weights from 1,4 to 63 t and lengths unto 4400 mm.

Fig. 1 – Map of Europe.

Fig. 1 – Carta dell'Europa.

All steel is uphill cast into groups of moulds. The quality range comprises more than 800 different grades: aluminium killed, low to high carbon content, manganese-, chromium-, molybdenum-alloyed desulphurised , vacuumdegased and calcium treated.
The AC - 70 t furnace with a shell diameter of 5180 mm and an electrode pitch circle diameter of 1220 mm works with 20 inche electrodes and is equipped with the following:

- 45 MVA transformer
- water cooled wall and cover, TW 2000 with heat recovery
- nose tapping
- 4 bottom stirring plugs
- 3 wall burners with post combustion
- lance manipulator with 1 carbon and 2 oxygen lances
- current conducting aluminium electrode arms
- electrode spray cooling

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** Products and/or trademarks of MINTEQ® International GmbH.

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Paper presented at the 2nd International Conference & Exhibition on New Developments in Metallurgical Process Technology, Riva del Garda, Italy 19-21 September 2004

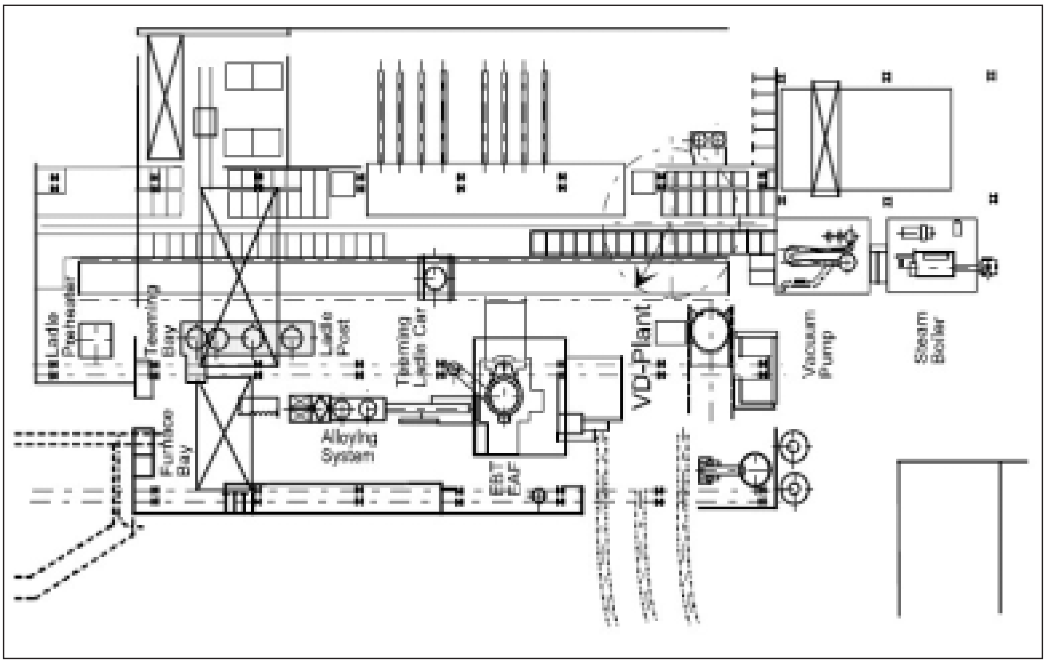

Fig. 2 – Plan of Stahlwerk Bous GmbH.

Fig. 2 – Pianta dell'acciaieria Stahlwerk Bous GmbH.

- waste gas spray cooling
- furnace enclosure
- process computor
- alloy hopper
- neural network for optimal control of energy input.

OLD AND NEW REFRACTORY METHODS

Refractory application was a major cause of downtime at Bous. This included both the furnace re-lining and refractory maintenance by both gunning and fettling.
The classic gunning maintenance practice involves very hard manual labour to manipulate lance in front of the furnace, which requires 2 operatives.
For material application a rotor or pressure chamber gunning machine was required which had a maximum conveying capacity of 80 kg/min. This meant that gunning, for example one tonne of refractory material to maintain the furnace slag line would take approximately 12.5 minutes. In addition due to the varying distances and angles necessary to apply the material to the slag line it was not possible to apply material uniformly at the optimum angle, as a result rebound levels of up to 30% could result. Hence in order to effectively apply 1 tonne of material to the slag line, 1.3 tonnes had to be gunned. This typical increased the maintenance time by 3.75 minutes, giving a total time for the refractory maintenance of the slag line of 16.25 minutes per heat. Depending on the refractory condition of the furnace, maintenance times of up to double this figure were possible.
If the refractory wear becomes too severe the furnace has to be taken out of service for refractory repair. Every week a brick repair was carried out. A brick repair would take around 8 hours, including the time to breakout the worn bricks, which required a gang of bricklayers.
Bous decided to change this practice with the aim of decreasing total refractory costs and increasing furnace productivity. The aim was to reduce both the number of and the time taken for gunning repairs and to extend the production period between brick repairs to two weeks.
Together with Minteq International GmbH the fully automatic EAF refractory maintenance system (MINSCAN™***, LaCam™*, SCANTROL™**) was installed in January 2003. The concept was designed with a view to repairing EAF refractory linings rapidly and efficiently.
The system includes equipment, service and materials to increase furnace steel production and reduce refractory costs.
The system has now been optimised for 1 _ year and has significantly reduced the maintenance time and refractory consumption of the electric arc furnace at Bous.

FULLY AUTOMATIC MAINTENANCE SYSTEM

The system comprises the following three components (Fig. 3):
- A LaCam™ laser scanner to measure the residual refractory thickness of the furnace.
- Enhanced MINSCAN™ robotic maintenance system to repair the refractory lining in different areas of the EAF.
- SCANTROL™ interface module, linking the above-mentioned components, to evaluate the measurement data and control the robotic maintenance unit.

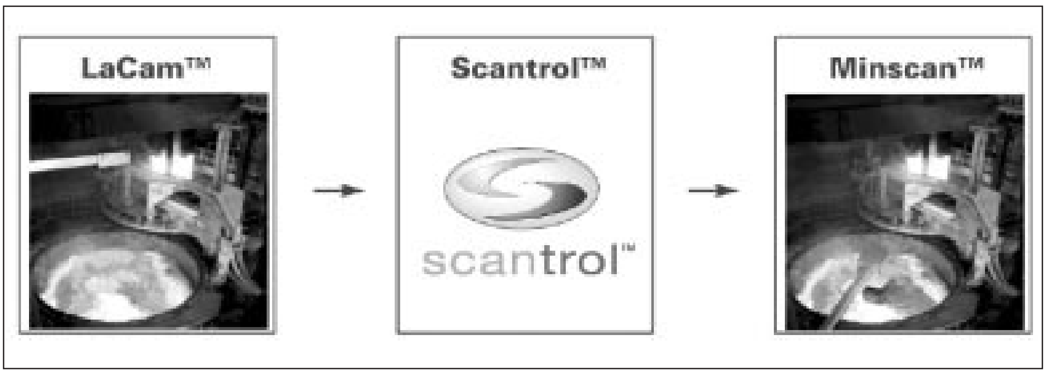

Fig. 3 – Components of the fully automatic maintenance system.

Fig. 3 – Componenti del sistema automatico di manutenzione del refrattario.

EQUIPMENT

LaCam™ Laser Scanner

The laser-based profile-measuring system has been developed for non-contact measurement of refractory linings in metallurgical reaction and transport ladles.
The scanning unit is installed in a rugged cylindrical steel housing (see Fig. 4). Its measuring principle is based on accurate range finding by means of a pulsed semiconductor diode laser with electrooptical ranging capability and a biaxial beam scanning mechanism. The 3D images are generated by performing a number of independent laser ranging measurements in different yet well-defined angular directions. These ranging data, together with associated angles, form the basis of the 3D images.
A three-dimensional framework of the furnace inner surface is created with, typically, 200,000 ranging points being scanned within 20 seconds.
The built-in industrial PC evaluates the residual refractory thickness by comparing it with a previous reference measurement.

LaCam™ Manipulator

At Bous the laser manipulator, is installed 9 m above the UHP furnace outside of the Dog House. The manipulator essentially comprises an arm with two guides and a cooled box to accommodate the laser scanner. A powerful geared motor enables the manipulator to traverse at high speed, so as to minimise the overall time taken for the measuring procedure.
Additional cooling systems permit unlimited measurement, even at extremely high furnace temperatures. If a laser measuring is to be done (Fig. 5) the manipulator drives into the Dog House and makes two measurements in different positions. The whole process takes 35 seconds.

Minscan application equipment

Many improvements had to be made to the original MINSCAN™ to meet the requirements of fully automatic gunning based on LaCam™ measurements. In addition the small amount of available space and the small furnace diameter meant the classic MINSCAN™ had to be redesigned.
A complete new design of MINSCAN™ was produced with much faster and smoother movement. The gunning head and water mixing system had to also be re-designed for this furnace. To enable for the gunning head to locate the correct required position in the furnace a co-ordinating system was required. This necessitated the design of a completely new software system for the MINSCAN™.
Due to the very small Dog House the MINSCAN™ had to be split into three separate components, consisting of the manipulator, the silos and hoppers and thirdly the hydraulic system.
The manipulator is positioned in the Dog House on a 2.3m high platform. This was required to ensure that there was no interference with other aspects of the furnace. This area was also the most frequent entry point to the Dog House to take samples and temperature measurements during the process.
The silos and hoppers are located on a platform outside of the Dog House (Fig. 6).
The hydraulic system with the tank, motors and cooling are positioned outside the Dog House on the ground.
The gunning head can perform a continuous 360° rotational and simultaneous vertical movement from the furnace centre to the upper edge of the furnace water-cooling panels.
Incorporated inside the gunning head is a newly developed eccentric jet mixing nozzle MINJET designed to thoroughly wet the material at high speeds whilst preventing clogging and pipe drip.
The new cooling technique ensures that the maintenance operation can operate continuously without any temperature restrictions.
This equipment guarantees the application of gunning and fettling material in a precise, efficient safe and rapid manner.

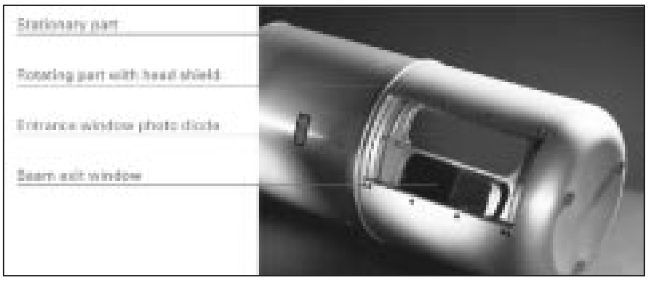

Fig. 4 – LaCam™ laser head.

Fig. 4 – La sonda laser LaCam™.

Fig. 5 – The LaCam™ manipulator unit.

Fig. 5 – Il gruppo manipolatore della sonda LaCam™ manipulator unit.

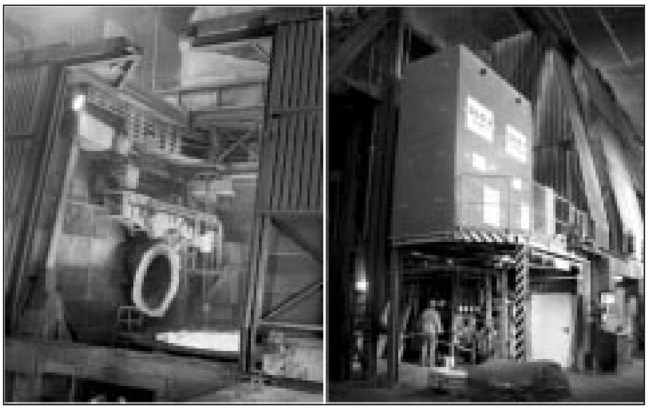

Fig. 6 – The new robotic maintenance unit: MINSCAN™.

Fig. 6 – Il dispositivo robotizzato di manutenzione MINSCAN™.

REFRACTORY PRODUCTS

The MINSCAN™ system can work with gunning and dry bottom material at very high rates under both hot and cold conditions. These materials are specially engineered for improved flowability, wetability and plasticity. The unique particle sizing and binder package allows outstanding adhesion to the furnace substrate, thus improving on-wall density and

minimising rebound. As a result, material durability is increased which, in turn, reduces maintenance operations and increases furnace availability.
The chemical composition of the M-Frit KK**, M-Frit** and MgO bottom construction and repair materials has been developed to ensure an optimum balance between fusion behaviour and adhesive strength.
Quantum** gunning material is used to maintain and repair the slag zone. It has been successfully redesigned for fully automatic gunning using the MINJET. The result is a much higher application rate. The use of pure MgO sources and the synthetic additives contributes resistance against hot erosion and slag attack and leads to extremely high material durability.
The binder system does not contain any phosphate, ensuring that the phosphorus content in the steel is not affected.
Interface between laser and manipulator: Scantrol™
The SCANTROL™ interface module transforms the measurement data from the laser scanner in such a way that this information is evaluated, and then a maintenance strategy is derived to control the robotic maintenance unit.

EVALUATION

The diagram in Fig. 7 shows a flowchart for the process.
The operator at the EAF initiates the measuring procedure. When the exact position of the furnace has been determined automatically from the laser measurement by means of 3D matrix , the working-lining measuring points are filtered out and transformed into a coordinate system for the furnace. The calculation of the residual brick thickness takes place on the basis of a comparison profile (permanent lining). The individual measuring points in partial, high-resolution fields, which are defined in terms of cylinder co-ordinates and distributed uniformly over the vessel area potentially requiring repair, are then combined. The system determines the co-ordinates with minimum residual brick thickness in relation to three-dimensionally depicted sectors. Threshold values that the operator defines for the permissible residual brick thicknesses, per sector, serve as the basis for deriving the matrix of the areas requiring repairs areas in which the residual brick thickness is less than the
appropriate threshold value.
The operator sets the optimisation sequence (duration, material consumption, degree of restoration) and starts the calculation of the optimised maintenance procedure so that the system carries out the maintenance automatically:

- Special matrix formula combine the fragmented, high-resolution structures of the fields requiring repair into three-dimensionally coherent, compact structures.
- The sizes and sequences of the rectangular areas requiring repair as well as the type of repair materials and application rate (applied thickness) are determined by means of strategies designed to optimise the time taken, material consumption and degree of restoration, and by taking into account the physical properties of the mixes used for the repair (application from bottom to top, setting duration, max. thickness of application).
- The manipulator co-ordinates for the areas requiring repair are transmitted in the form of a telegram to the PLC unit of the MINSCAN™ system.
- The MINSCAN™ system carries out its maintenance routine fully automatically, i.e. the right product is "expertly" applied at the exact location in the required layer thickness.

These parameters are integrated in the preventive maintenance programme, thereby harmonising consumption and operating efficiency.

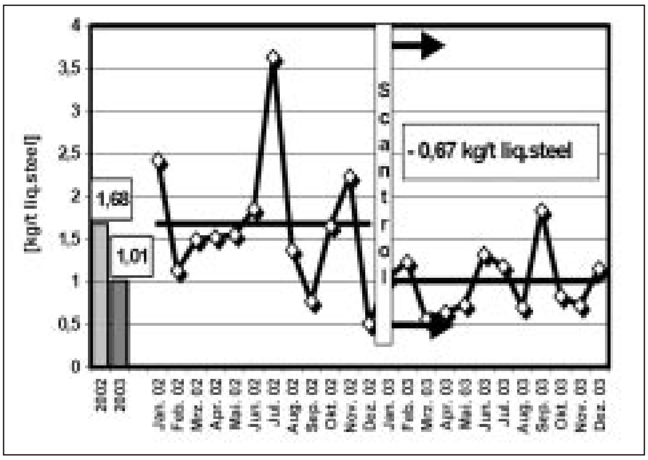

Fig. 7 – The maintenance process including Scantrol™.

Fig. 7 – Il processo di manutenzione che comprende Scantrol™.

VISUALISATION

A monitor in the control pulpit is used for the visualisation of the measured residual refractory thicknesses and the parameters for the fully automatic maintenance process in the EAF. The actually measured residual refractory thicknesses (wall, bottom) are shown in the left-hand half of the display (Fig. 8). Visible on the right-hand side are the maintained areas or the thicknesses of the refractory (wall, bottom) after a pre-calculated, automatic maintenance process.

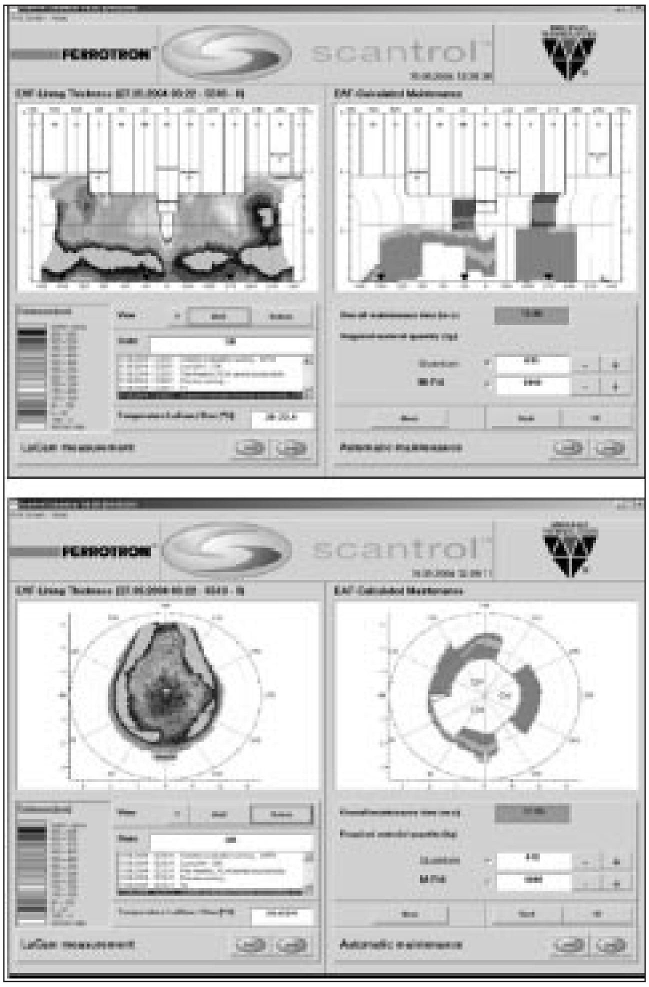

Fig. 8 – Operator console and display.

Fig. 8 – Il quadro di controllo e il monitor dell'operatore.

The system permits a simple menu-driven dialogue that enables the operator to read off the exact amounts of Quantum** (slag zone) and M-Frit** (banks, bottom) materials and the total maintenance time (including manipulator movements).
If the operator concurs with the maintenance procedure, he can initiate it directly at the push of a button. If the maintenance time or material quantity appears excessive to him, because of production influences, for example, then he is able to alter the time or quantity. At the same time the residual maintained refractory areas and thicknesses are recalculated and displayed afresh on the right of the screen. Once he has given his approval, the repair and maintenance process is then carried out fully automatically.
The operator thus has the possibility at any time to adjust the maintenance process to the situation at the furnace.
The exact measurements of the residual thickness in the whole furnace by the La Cam™* system provide the operator with exact information about the state of the refractory.
The measurement is carried out at least three times per day. Profiles of the refractory wear in the EAF are being determined and evaluated online. The measurements made during a furnace campaign are evaluated and depicted in the following Figure (Fig. 9). These Figures indicate the thickness of the slag zone, banks and bottom of the EAF. The various colours symbolise the diverse residual thicknesses. The black horizontal line symbolizes the slag zone and the water-cooled panel are represented in white.
In the Figure 9 you can sea the main problem zones in the furnace are behind the door, the phase 2 and 3 in the slag zone and the banks.
Accelerated refractory wear in the various sectors of the EAF is identified directly. With the aid of the software it is possible to superimpose the different furnace refractory states horizontally and vertically (Fig.10) at different angles

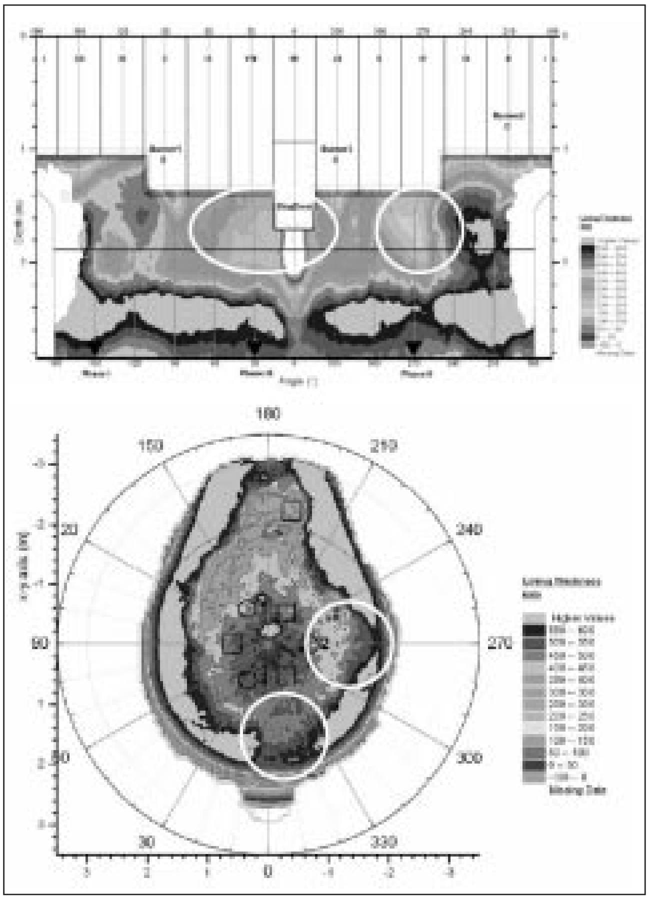

Fig. 9 – Representation of the wall and bottom.

Fig. 9 – Rappresentazione della parete e del fondo.

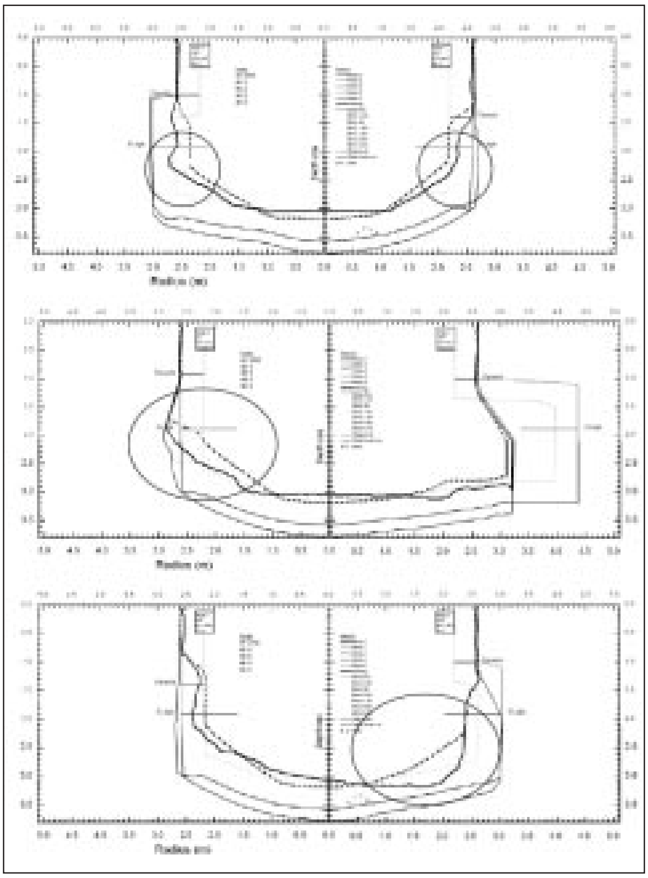

Fig. 10 – Horizontal cross sections at start up and after the 65 heats.

Fig. 10 – Sezioni trasversali orizzontali allo start up e dopo 65 processi.

and levels, thereby generating a refractory wear profile as a function of time. The software immediately pre-calculates the refractory wear. Further you can see the original lining (thick black line in Fig.10) when the furnace was new and the permeable blocks in bottom are also shown.

RESULTS

The fully automatic EAF maintenance system was introduced in January 2003. In the following figures we will see the average values of some significant consumptions in the year 2002 before installing SCANTROL™ and the year 2003 after installation. Finally we will calculate the savings and the total net savings.
1. refractory maintenance time
2. brick consumption
3. gunning material consumption
4. bottom/bank cold repair consumption
5. bottom/bank hot repair consumption
6. total savings.

1. Refractory maintenance time

Fig.11 shows the refractory maintenance time in min/heat. The refractory maintenance time drops down from 3.81 in 2002 to 3.10 in 2003 by 0,71 min/heat or 18.6%.

2. Brick consumption

In consequence of the successful use of SCANTROL™* and a new strategy of slag composition the refractory working period of the furnace was doubled. This gave a reduction of the brick consumption from 3.37 in 2002 to 1.86 in 2003 by 1.51 kg/t liquid steel or 44.8% (Fig. 12).

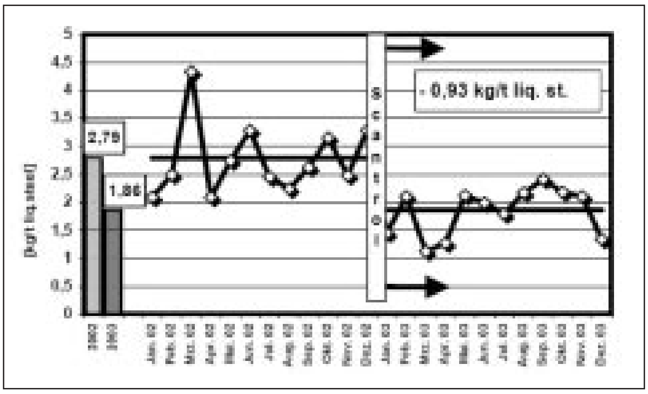

Fig. 11 – Refractory maintenance time before and after implement SCANTROL™.*

Fig. 11 – I tempi di manutenzione del refrattario prima e dopo l'introduzione del sistema SCANTROL™.*

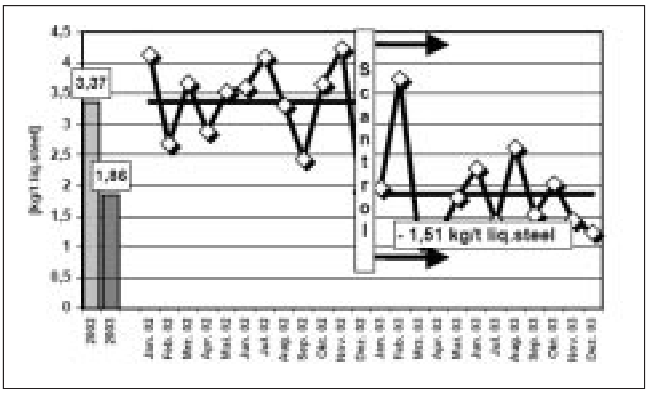

Fig. 12 – Brick consumption before and after implement SCANTROL™.*

Fig. 12 – Consumo di mattone prima e dopo l'introduzione del sistema SCANTROL™.*

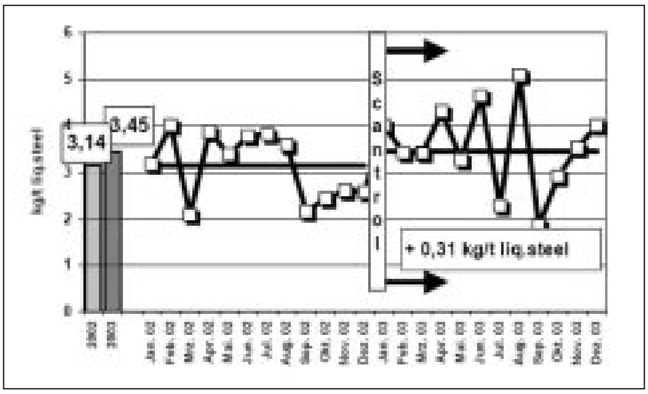

Fig. 13 – Gunning consumption before and after implement SCANTROL™.*

Fig. 13 – Consumo di miscele per gunning prima e dopo l'introduzione del sistema SCANTROL ™.*

3. Gunning consumption

With the new controlled system it is possible to effectively maintain the refractories in areas of the furnace that could not be reached using a hand lance. These areas include behind the furnace door, the door pillars and areas to the left and right of the door. Additionally a larger proportion of the banks are now maintained using gunning compared to the situation before the introduction of the SCANTROL when fettling maintenance would have been used. As a result of these factors the consumption of gunning material following the introduction of the automatic system has increased from 3.14 Kg/t of liquid steel in 2002 to 3.45 in 2003, an increase of 0.31 kg/t liquid steel or 9.9%.

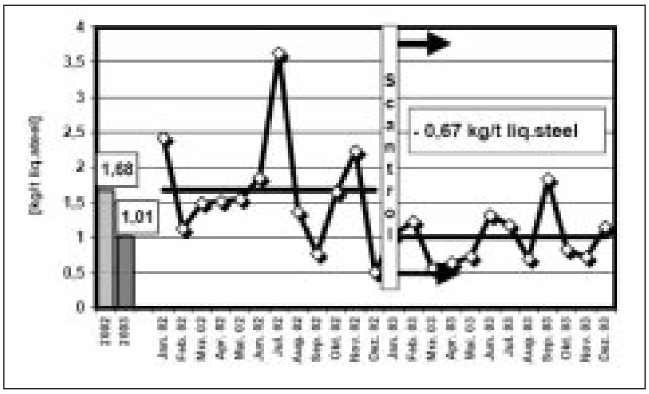

Fig. 14 – Bottom/bank cold repair consumption before and after implement SCANTROL™.*

Fig. 14 – Consumo per riparazioni a freddo prima e dopo l'introduzione del sistema SCANTROL ™.*

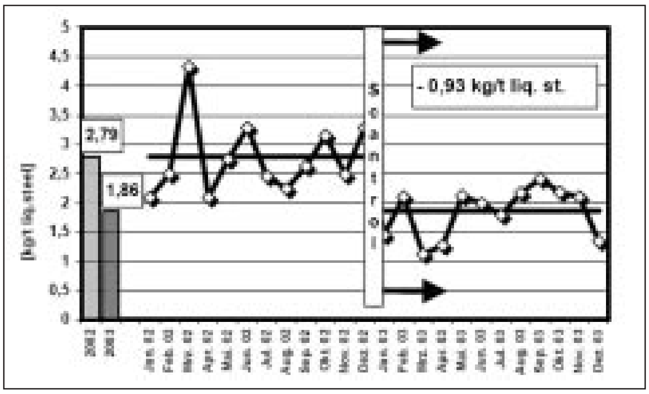

Fig. 15 – Bottom/bank hot repair consumption before and after implementation of SCANTROL™.*

Fig. 15 – Consumo per riparazioni a caldo prima e dopo l'introduzione del sistema SCANTROL ™.*

4. Bottom/bank cold repair consumption

The Fig. 14 depicts the consumption of the bottom/bank cold repair materials. The consumption decreases from 1.68 in 2002 to 1.01 in 2003 by 0.67 kg/t liquid steel or 39.9%.

5. Bottom/bank hot repair consumption

Influenced by the above mentioned new practice with the gunning material there is an significant effect on the consumption of the bottom/bank hot repair material. Fig. 15 shows a reduction of the bottom/bank hot repair consumption from 2.79 in 2002 to 1.86 in 2003 by 0.93 kg/t liquid steel or 33.3%.

6. Total savings

Figure 16 shows the costs and the total net savings after introduction of SCANTROL™*.

Associated costs are :

1. operating lease of LaCam™*, SCANTROL™*, MINSCAN™**
2. increased consumption of gunning material,
3. price of the new bottom/bank hot repair material,
4. additional consumption of regenerated Mg O.

The benefits are :

1. decreased bottom/bank cold repair material,
2. reduced brick consumption,
3. less refractory maintenance time ,
4. doubling of the production period of the furnace between brick relines,
5. additional production shifts.

Fig. 16 – Savings.

Fig. 16 – Risparmio complessivo.

		2002 Without SCANTROL™*	2003 With SCANTROL™*	Consumption Additional %	Less %
Rental equipment	%	0	100	100	
Slag conditioning	%	0	100	100	
Gunning material	kg/t liq. steel	3,14	3,45	9,9	
Bank/Bottom hot repair	kg/t liq. steel	2,79	1,86		-33,3
Bank/Bottom cold repair	kg/t liq. steel	1,68	1,01		-39,9
Bricks	kg/t liq. steel	3,37	1,86		-44,8
maintenance time	min/heat	3,81	3,1		-18,6
Refractory repair shifts	n		-22		
Additional shifts	n		-22		
SPEC. NET SAVINGS	**€/t. liq. steel**				**1,39**
TOTAL NET SAVINGS	**€/year**				**321.271**

The resulting specific net-savings are 1,39 _/t liquid steel. The resulting total net savings are 321271 _/year.

CONCLUSION

The new fully automatic EAF refractory maintenance system was installed in Bous steel plant in January 2003.
After a short period to optimise the operation to meet the specialised requirements of Bous, the equipment has operated effectively with superior availability.
The functionality of the SCANTROL™** system (laser driven measurement of refractory thickness, visual representation of scanned results and automatic material application) has significant enhanced productivity, working conditions and decision making capabilities of steel operators.
The overall effect at Bous has included:

- Reduction in total refractory consumption
- Reduction in refractory maintenance time
- The ability to effectively maintain all areas of the furnace
- Doubling the available production period between brick relines
- Reduction the requirement for additional shifts has been reduced
- Improved operational safety
- Elimination of hand lance manual operation.

A B S T R A C T

SISTEMA AUTOMATICO DI MANUTENZIONE DEL REFRATTARIO

Parole chiave:
refrattari, siderurgia, produzione

I continui cambiamenti nella sfera economica e la sempre maggiore pressione competitiva hanno indotto i produttori di acciaio a introdurre misure innovative al fine di ridurre i costi.
La Stahlwerk Bous / Saar GmbH, negli ultimi anni ha perseguito questa strategia in modo soddisfacente.
In collaborazione con la Minteq International GmbH è stato messo a punto e introdotto un concetto totalmente innovativo di manutenzione del forno ad arco, che ha portato all'installazione – nel 2003 – di un sistema di manutenzione del refrattario totalmente automatico.
Lo sviluppo di un sistema di manutenzione automatico e continuo del refrattario del forno ad arco progettato su misura per soddisfare le attuali esigenze produttive della Stahlwerk Bous hanno portato all'eliminazione degli svantaggi di un sistema di manutenzione non continuativa.
Il sistema consiste in uno scanner laser, denominato La-Cam™, che consente di misurare lo spessore residuo del refrattario del forno, unitamente ad una versione innovativa della tecnologia robotica MINSCAN™**. Questi componenti sono stati collegati fra loro mediante un modulo di interfaccia denominato SCANTROL™*, in grado di valutare dati relativi alla misura e di controllare il sistema di manutenzione robotizzato, facendo 'sì che venga applicata automaticamente la corretta quantità di materiale refrattario laddove necessario.*
Sono stati così ottenuti significativi risultati positivi in termini di riduzione dei tempi di manutenzione, riduzione dell' utilizzo di materiale refrattario, riduzione delle riparazioni nonché un sensibile risparmio dei costi energetici, che hanno consentito di avere di conseguenza una migliore disponibilità e una maggiore produttività del forno ad arco.