Continuous changes in the economic environment and increasing competitive pressures require steel producers to introduce innovative measures to reduce costs. Stahlwerk Bous/Saar GmbH, part of the steel section in Georgsmarienhütte Holding, has successfully pursued this strategy over many years. More recently, working with Minteq International GmbH, a new concept of automatic arc furnace refractory maintenance was developed to eliminate the disadvantages inherent in intermittent refractory maintenance.

DESCRIPTION OF THE STEEL PLANT
Stahlwerk Bous GmbH is located on the banks of the river Saar in south west Germany. It was built in 1961 and produces more than 260,000tpa of round, polygonal, rectangular, square, cylindrical and conical uphill casting ingots per year for seamless tube mills and forgings, with weights from 1.4 to 63 tonnes. The quality range comprises more than 800 different grades of aluminium killed, low to high carbon, manganese, chromium and molybdenum-alloyed steels, together with desulphurised, vacuum-degassed and calcium treated grades.

The 70t AC EAF has a shell diameter of 5,180mm and an electrode pitch circle diameter of 1,220mm and 20in electrodes, and is equipped with the following:
- 45 MVA transformer
- Water cooled wall and roof, TW 2000 with heat recovery
- Nose tapping
- Four bottom stirring plugs
- Three wall burners with post combustion
- Lance manipulator with one carbon and two oxygen lances
- Current conducting aluminium electrode arms
- Electrode spray cooling
- Waste gas spray cooling
- Furnace enclosure
- Process computer
- Alloy hopper
- Neural network for optimal control of energy input.

REFRACTORY MAINTENANCE METHODS
Refractory maintenance was a major cause of downtime at Bous, both for furnace re-lining and refractory maintenance by gunning and fettling. Classic gunning maintenance practice involves very hard manual labour to manipulate the lance in front of the furnace and requires two operatives; and for material application a rotor or pressure chamber gunning machine was required which had a maximum conveying capacity of 80kg/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, resulting in rebound levels of up to 30%. Hence, in order to effectively apply 1t of material to the slag line, 1.3t had to be gunned. This typically increased the maintenance time by 3.75 minutes, giving a total time for slag line maintenance 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 refractory wear became too severe the furnace had to be taken out of service for repair and every week a brick repair was carried out which would take around 8 hours, including the time to breakout the worn bricks. 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 an automatic EAF refractory maintenance system was installed in January 2003. The concept was designed with a view to repairing EAF refractory linings rapidly and efficiently. The system, which includes equipment, service and materials to increase furnace steel production and reduce refractory costs has now been optimised and has significantly reduced the maintenance time and refractory consumption.
FULLY AUTOMATIC MAINTENANCE SYSTEM
The system comprises the following three components:

- A LaCam® laser scanner to measure the residual refractory thickness of the furnace (see Figure 1)
- An enhanced MINSCAN™ robotic maintenance system to repair the refractory lining in different areas of the EAF (see Figure 2)
- A SCANTROL™ interface module, linking the above-mentioned components, to evaluate the measurement data and control the robotic maintenance unit.

LaCam laser scanner
The laser-based profile measuring system has been developed for non-contact measurement of refractory linings in metallurgical reaction vessels and transport ladles. The scanning unit is installed in a rugged cylindrical steel housing. Its measuring principle is based on accurate range-finding by means of a pulsed semiconductor diode laser with electro-optical 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 9m above the furnace outside 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. When a laser measurement is to be done the manipulator drives into the dog house and makes two measurements in different positions, taking only 35 seconds (see Figures 3a and 3b).

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 that the classic MINSCAN had to be re-designed with a much faster and smoother movement and a new gunning head and water mixing system. To enable the gunning head to locate the correct required position in the furnace, a co-ordinating system was required which necessitated the design of a completely new software system.

Due to the very small dog house the MINSCAN had to be split into three separate components: the manipulator, the silos and hoppers, and the hydraulic system. The manipulator is positioned in the dog house on a 2.3m high platform to ensure that there was no interference with other aspects of the furnace operation. 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. 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’.
to thoroughly wet the material at high speeds while 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.

**Scantrol** This is an interface between laser and manipulator which 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.

**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, and 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, which is used to maintain and repair the slag zone, has been successfully redesigned for fully automatic gunning using the MINJET, resulting in a much higher application rate. The use of pure MgO and the synthetic additives contribute to resistance against hot erosion and slag attack, leading to extremely high material durability. The binder system does not contain any phosphate, ensuring that the phosphorus content in the steel is not affected.

**EVALUATION**
*Figure 4* 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 a 3D matrix, the working-lining measuring points are filtered out and transformed into a co-ordinate system for the furnace. The calculation of the residual brick thickness takes place on the basis of a comparison profile of the permanent lining. The individual measuring points in partial, high-resolution fields are defined in terms of cylinder co-ordinates and distributed uniformly over the vessel area potentially requiring repair, and 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 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, as follows:

- Special matrix formulae 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, maximum 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, ie, the right product is ‘expertly’ applied at the exact location in the required layer thickness. These parameters are integrated in the preventative maintenance
programme, thereby harmonising consumption and operating efficiency.

**VISUALISATION**

A monitor in the control pulpit is used for the visualisation of the measured residual refractory thicknesses and the parameters for the refractory maintenance process. The measured residual refractory thicknesses (wall and bottom) are shown in the left-hand half of the display (see Figures 5a and 5b). The maintained areas or the thicknesses of the refractory (wall, bottom) after a pre-calculated, automatic maintenance process are seen on the right-hand side.

The system permits a simple menu-driven dialogue that enables the operator to read off the exact amounts of materials (Quantum for the slag zone and M-Frit for banks and bottom), 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, for example, because of production influences, he is able to alter the time or quantity. At the same time the residual maintained refractory areas and thicknesses are recalculated and re-displayed on the right of the screen. Once he has given his approval, the repair and maintenance process is then carried out 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 LaCam system provide the operator with exact information about the state of the refractory. The measurement is carried out at least three times per day and profiles of the refractory wear in the EAF are being determined and evaluated online.

### Table 1 Summary of savings and costs

<table>
<thead>
<tr>
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<th>2002 Without SCANTR</th>
<th>2003 With SCANTR</th>
<th>Consumption</th>
</tr>
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<tbody>
<tr>
<td>Rental equipment %</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Slag conditioning %</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Gunning material kg/tls</td>
<td>3.14</td>
<td>3.45</td>
<td>9.9</td>
</tr>
<tr>
<td>Bank/bottom hot repair kg/tls</td>
<td>2.79</td>
<td>1.86</td>
<td>-33.3</td>
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<tr>
<td>Bank/bottom cold repair kg/tls</td>
<td>1.68</td>
<td>1.01</td>
<td>-39.9</td>
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<tr>
<td>Bricks kg/tls</td>
<td>3.37</td>
<td>1.86</td>
<td>-44.8</td>
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<tr>
<td>Maintenance time min/heat</td>
<td>3.81</td>
<td>3.1</td>
<td>-18.6</td>
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<tr>
<td>Refractory repair shifts number/yr</td>
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<td>-22</td>
<td>-</td>
</tr>
<tr>
<td>Additional shifts number/yr</td>
<td>-</td>
<td>-22</td>
<td>-</td>
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</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Additional %</th>
<th>Less %</th>
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<tr>
<td>Specific net savings €/tls</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td>Total net savings €/yr</td>
<td>321,271</td>
<td></td>
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</tbody>
</table>
RESULTS

Figures 7 and 8 illustrate some average values of significant consumptions in 2002 before installing SCANTROL and in 2003 after installation. With the new system it is possible to effectively maintain the refractory 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. These data are summarised in Table 1.

Associated costs are:
- Operating lease of LaCam, SCANTROL, MINSCAN
- Increased consumption of gunning material
- Cost of the new bottom/bank hot repair material
- Additional consumption of regenerated MgO

The benefits are:
- Decreased bottom/bank cold repair material
- Reduced brick consumption
- Less refractory maintenance time
- Doubling of the production period of the furnace between brick relines
- Additional production shifts

The resulting specific net-savings are 1.39€/t liquid steel, equivalent to 321,271€/year.

CONCLUSIONS

The automatic EAF refractory maintenance system was installed in the 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 excellent availability. The functionality of the SCANTROL system providing laser driven measurement of refractory thickness, visual representation of scanned results and automatic material application, has significantly enhanced productivity, working conditions and decision-making capabilities of steel plant 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
- The requirement for additional shifts has been reduced

Fig. 6a & b Vertical cross-sections at different vessel positions

The measurements made during a furnace campaign are evaluated and depicted in Figures 5a and 5b. 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 indicates the slag zone, and the water-cooled panel are represented in white. It can be seen in that the main problem zones in the furnace are behind the door, the phase 2 and 3 electrodes in the slag zone and the banks.

Accelerated refractory wear in the various sectors of the EAF is identified directly and with the aid of the software it is possible to superimpose the different furnace refractory states horizontally and vertically at different angles and levels as shown in Figures 6a and 6b, thereby generating a refractory wear profile as a function of time. The software immediately calculates the refractory wear. The original lining (thick black line) and the permeable blocks in bottom are also shown.
STEELMAKING

- Improved operational safety
- Elimination of hand lance manual operation

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Technologies for electric steel plants

Injection Systems
- Injection installations for fine carbon with 1-4 conveying lines for the forming of foaming slag.
- Injection installations for filter dusts, additives into furnaces or ladles.
- Injection of coarse lime via the furnace roof for the protection of the hot spots.

Gunning Systems
- Gunning robots for the quick and effective repair of EAF, ladles etc.
- Pressure vessel and rotor gunning machines for all kinds of refractory repairs.
- Centrifugal slinger.