Innovative concepts for surface grinding and automatic inspection of special bar quality products

Prior to further processing of semi-finished steel products, it must be ensured that work piece surfaces are free from scale and flaws. High-pressure grinding is proven to be the optimal technology for removing scale, cracks and other surface defects. The grinding of surfaces of SBQ products, however, needs quite specific requirements from the grinding facility – in particular, if surface cracks are detected beforehand, the ground surface needs to be inspected automatically right after grinding. By means of two executed projects, the concepts are described for fully automated grinding lines developed by BRAUN to fulfil respective demands.

Authors: Norbert Asamer and Gerhard Richter
BRAUN Maschinenfabrik GmbH

BASIC PRODUCTION REQUIREMENTS

The surface of cast, forged or rolled products may contain cracks, inclusions and scale. Depending on steel grade and application, these imperfections may need to be removed prior to further processing. High-pressure grinding is proven to be the most reliable and effective technology to achieve fault-free surfaces. This is due to its reliability, high capacity and flexible applicability, but also to its high environmental compatibility, it is superior to other techniques, such as manual grinding, robotic grinding or flame scarfing.

Depending on the type, quantity and distribution of the surface flaws, either the entire surface or only certain areas of the work piece must be ground. We distinguish between the following three basic applications for high-pressure grinding:

- Bright grinding of the entire surface
- Grinding of the corners (for work pieces with squared cross-sections)
- Controlled grinding of partial surface flaws

Hot-pressed grinding wheels (see *Figure 1*) are the tools used for the high-pressure grinding process. In order to meet the requirements of the grinding application with regards to surface roughness, grinding depth, brightness of surface, etc, it is necessary to select the proper wheel specification (ie, type and size of abrasive grains).

In order to achieve a high-quality grinding result, however, the grinding machine, too, must comply with certain requirements:

Grinding pressure The machine must be designed in a way that the grinding pressure can be selected in accordance with the given application. Furthermore, it is of great advantage if it can be operated with the highest possible grinding pressures in order to achieve high material removal rates. In either case, it is essential to keep the set grinding pressure constant, in particular if the surface of the work piece is uneven.

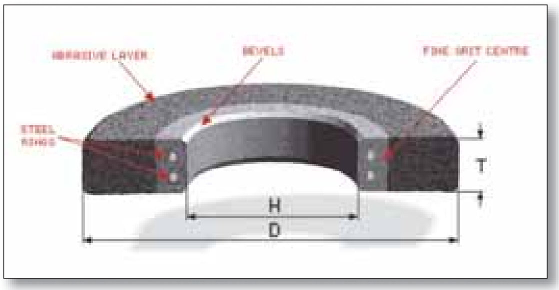

Fig 1 Basic structure of a hot-pressed grinding wheel

Peripheral speed of the grinding wheel To achieve the desired material removal rate, a long service life of the grinding wheel, as well as the desired grinding quality, the selection of the proper peripheral speed of the grinding wheel is important. The majority of grinding wheels are rated for a peripheral speed of max. 80m/s. Thus, the grinding machine must be capable of achieving this permissible speed. In particular, the selected speed must be kept constant as the wheel diameter reduces as it wears.

Relative speed of the work piece in relation to the grinding wheel The relative speed of the work piece in relation to the grinding wheel should be as high as possible. This is not only important for a high removal rate, ▷

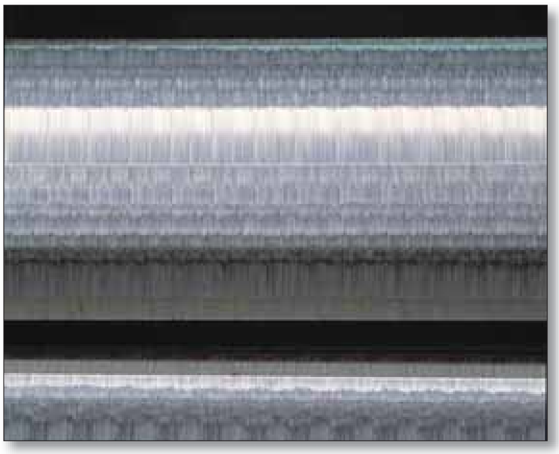

Fig 2 **Ideal grinding finish (tool steel)**

Fig 3 **Decarburisation-free work piece surface (tool steel – 1,500 : 1 magnification)**

Fig 4 **HP grinding machine at BÖHLER Edelstahl**

but in particular for the quality of the ground surface. If the relative speed is too low, the work piece can become locally overheated if the wheel dwells too long at a certain position on the surface. Especially for materials with higher carbon contents, this could lead to discolourations and local surface hardening. Ideal grinding results are shown in *Figures 2* and *3*.

Furthermore, this high relative speed must be reached as quickly as possible. This means that the grinding machine must be able to accelerate rapidly.

FUNDAMENTALS AND KEY DESIGN FEATURES OF BRAUN'S HP GRINDING MACHINES

BRAUN Maschinenfabrik developed its HP (high-pressure/high-performance) grinding technology in 1998. The first application was a multifunctional facility for bright, corner and flaw grinding of billets of various dimensions and material grades at BÖHLER Edelstahl, Kapfenberg, Austria, using grinding wheels with a starting diameter of 610 mm (see *Figure 4*).

Throughout the design of this first HP grinding facility, BRAUN tried its utmost to use latest technical advances available at the time and to develop a substantially improved design. Looking back at that challenging project, it was of great advantage that this application posed some special requirements, such as to deal with occasionally badly distorted billets, some small billet sizes – they tend to deflect during grinding – and a huge variety of materials, including many alloys sensitive to surface cracks and surface decarburisation. Furthermore, it was beneficial that BRAUN took into account operational experiences of the customer during planning and engineering of the new facility.

Since 2004, further improved HP grinding machines have been built for a variety of applications:

- Bright, corner and flaw grinding of carbon steel, stainless steel and titanium billets and blooms
- Longitudinal grinding of the outer surface of large-scale seamless steel tubes
- Helical grinding of round stainless steel electrodes and ESR ingots
- Bright, corner and flaw grinding of stainless steel and titanium ingots and slabs

Ultimately, the HP grinding machine developed in this way represents a new, innovative grinding concept. This concept fully and perfectly meets abovementioned key criteria **[1]**.

Essentially, the design is a table grinding machine. This means that the actual grinding unit is anchored to the foundation and the work piece to be ground is moved back and forth by a grinding carriage (the table). This basic structure features the following advantages compared to a pendulum grinding machine where the work piece to be ground is in a fixed position and the actual grinding unit – the pendulum – is moved back and forth:

- Significantly higher stability of the grinding unit
- Excellent and consistent visibility for the operator who sits in a soundproof control booth
- A substantially better encapsulation of the grinding area as well as a controlled removal of swarf and dust (see *Figure 5*)

Other key design features of BRAUN's HP grinding machines are the following:

- Grinding drive with powerful, frequency-controlled motor allows maintaining a constant peripheral speed of the grinding wheel independent from the wheel diameter
- Specifically designed grinding spindle (bearing lubrication by means of pressurised oil recirculation and re-cooling system) ensuring a continuous heavy-duty operation and long service life
- Special wheel wear compensation system by measuring actual wheel diameter and automatic adjustment of peripheral speed
- Highly efficient and flexible design of the grinding head with weight-saving yet robust construction – allowing grinding pressures up to 1,400kg, exact adherence to pre-selected grinding pressure and uniform material removal – even if the surface of the work piece is rough or curved (see *Figures 6 & 7*)
- If the need arises, the possibility exists to retrofit elements, enabling stepless adjustment of the grinding head between 90 and 45° (grinding axis = pivot axis of grinding head, thus allowing re-adjustment of the grinding head even during the grinding process; see *Figure 6*)
- A sensitive and fast-reacting hydraulic-electronic grinding pressure control system ensures a uniform grinding pressure, even for uneven or curved work pieces
- Automatic and exact detection of both ends of the work piece ensures a smooth and jolt-free touch-down and lifting of the grinding wheel, which is especially important for longitudinal grinding
- A defined position of the work piece surface can be approached accurately (a precondition for a fully automatic flaw grinding)
- Comfortable, quiet control booth with special operator's seat and panoramic window for the highest degree of operational convenience and unrestricted visibility of the grinding process (see *Figure 8*)
- Clear, user-friendly process visualisation and data collection can also be connected to a higher-level process control system, if the need arises (see *Figure 9*)

METHODS FOR FULLY AUTOMATED GRINDING OF PARTIAL SURFACE FLAWS

Whilst BRAUN's HP grinding machine is designed for a fully automated operation and – alone – is able to accomplish this for bright grinding of the complete surface of the work piece and for corner grinding, for automated grinding of partial surface defects the machine needs to know the position of the flaw on the billet. Therefore, the surface defects must be detected prior to the grinding process. ▷

Fig 5 HP grinding machine at SAARSTAHL, Neunkirchen, Germany (grinding machine encapsulated by grinding cabin and connected to dust extraction system)

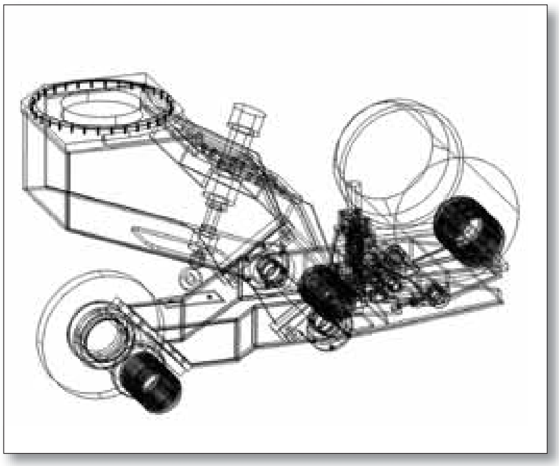

Fig 6 Grinding head (schematic)

Fig 7 Grinding head in operation

Fig 8 **Operator cabin**

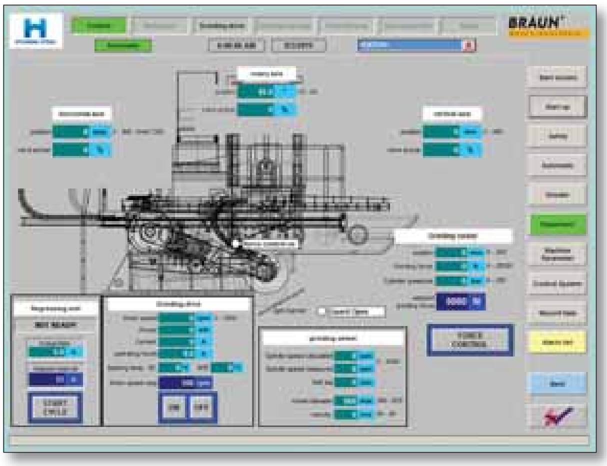

Fig 9 **Screen mask for process visualisation (example)**

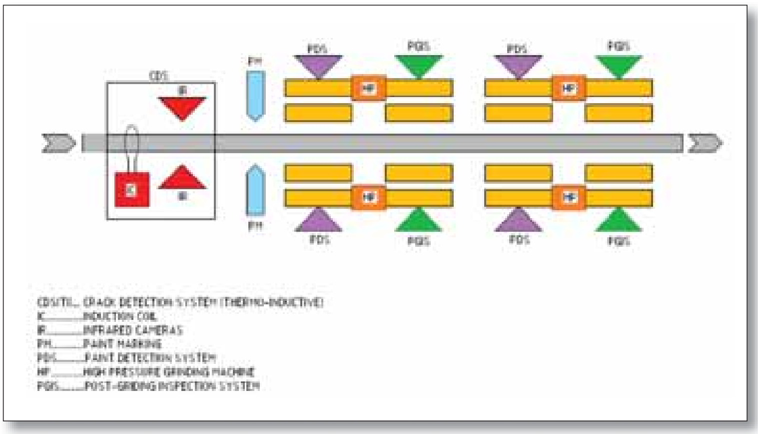

Fig 10 **Basic set-up for automated flaw grinding with thermo-inductive crack detection system and four HP grinding machines, without direct data transfer from crack detection system to grinding machine**

The conventional way of detecting surface cracks and removing them by grinding only the concerned areas surface is as follows: The surface is checked for cracks either manually (PT inspection) or by means of an automatic crack detection system (Magnaflux testing). Flaw grinding is then done manually by the operator of the grinding machine, whereby for the better recognition of the detected surface cracks, a UV lamp is installed inside the grinding cabin.

Since the grinding machine does basically allow automatically controlled grinding of certain spots or areas of the work piece surface (*see above*), BRAUN started to develop the possibility of really doing fully automated flaw grinding by evaluating the capabilities of the various crack detection systems available on the market. In addition an internal project team was formed which dealt with all other important issues, such as data management, product marking, product identification, etc.

The first concepts for an integrated solution for fully automated detection and grinding of surface defects were introduced in 2009 **[2]**. Additionally, more flexible solutions, (not strictly bound to a specific type of crack detection system), have been developed since then. Three basic solutions are described:

Example 1 Basic set-up for automated flaw grinding with one or more HP grinding machines, without direct data transfer from crack detection system to HP grinding machine (see *Figure 10*):

Crack detection can be done in the conventional way, ie, manually (PT inspection), semi-automatically using optical recognition systems whereby the grinding machine operator has to acknowledge the detected surface flaws, or fully automatically by means of a crack detection system. In the latter case, either a Magnaflux testing system or a thermo-inductive system can be used. Subsequently, the identified cracks are marked with coloured paint (either manually or by means of a paint marking device connected to the crack detection system). This allows automatic recognition of the crack positions by means of a paint detection unit connected to the HP grinding machine (during the first pass of the grinding carriage – the measuring pass – which is also used for exactly detecting the front and tail ends of the work piece). By this means, the actual flaw coordinates are determined by the PLC of the grinding machine.

After automatic grinding of the surface areas defined in this way, the ground areas can be checked by means of an optical post-grinding inspection system (mainly comprising a high-resolution camera and an electronic evaluation unit) connected to the PLC of the HP grinding machine. If a crack has not been removed completely, it can be reground immediately.

In *Figure 10*, the schematic of a thermo-inductive system is shown (in lieu of other crack detection systems) because it features several advantages, such as **[2]**:

- Work pieces can be tested fully automatically as well as with high reproducibility directly in the production line
- There is no need for preparation or pre-processing of the materials prior to the tests
- Any operation with pollution or toxic substances (partly required for Magnaflux testing) can be avoided
- The energy-intensive magnetisation of the work pieces can be omitted

For the thermo-inductive testing method, the work piece is penetrated with a high-frequency magnetic field, which in turn is produced with a high-frequency generator and an induction coil. In the thermo-inductive testing of long products (blooms or billets), the material runs through an induction coil. Four infrared cameras measure the temperature distribution on the entire surface of the work piece (see *Figure 11*).

During the run through the induction coil, the material is inductively heated for a short period of time. Cracks on or near the surface of the material represent barriers for the induced eddy current and therefore lead to hot spots. The inhomogeneous temperature distribution is observed with the infrared cameras. Finally, the material defects are detected by means of digital image processing algorithms **[2]** (see *Figure 12*).

The temperature increase along the edges of a crack depend on the crack depth: the deeper the crack, the higher the temperature increase. This enables the determination of the crack depth as a result of the observed temperature distribution **[3]**.

Example 2 Basic set-up for automated flaw grinding with one or two HP grinding machines, with thermo-inductive crack detection system and direct data transfer to grinding machine (see *Figure 13*).

In this case, a thermo-inductive system is directly mounted on a vertically adjustable mechanism at the outside of the grinding cabin of the HP grinding machine, whereby the induction coil is situated horizontally above the work piece to be checked. By this means, the right distance between induction coil and the work piece surface can be adjusted.

During the first measuring pass of the grinding carriage, not only the front and tail ends of the work piece are detected, the top surface of the work piece is simultaneously inspected by the crack detection system, too. The coordinates of the detected surface defects are then directly transferred to the PLC of the grinding machine. Subsequently, the determined surface areas of the work piece are ground. A re-inspection of the ground areas can also be done with the ▷

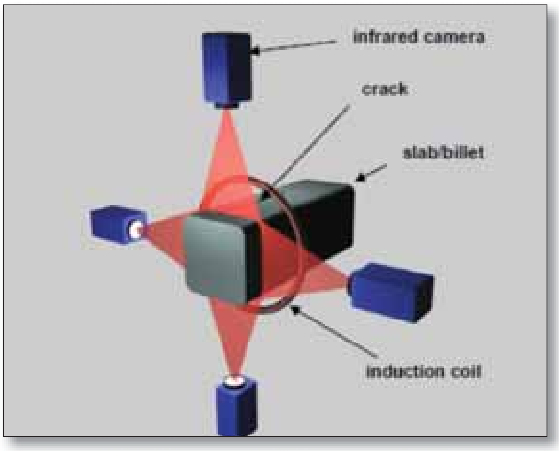

Fig 11 **Schematic of principal components for the thermo-inductive testing of square billets** ***(source: former vatron GmbH, Leoben, Austria)***

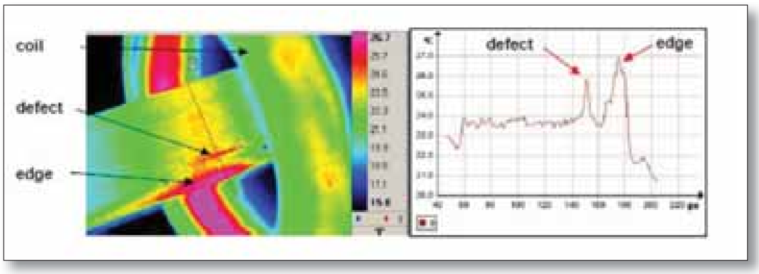

Fig 12 **Example of measuring the defective surface of a billet** ***(source: Institute of Automation, University of Leoben, Austria)***

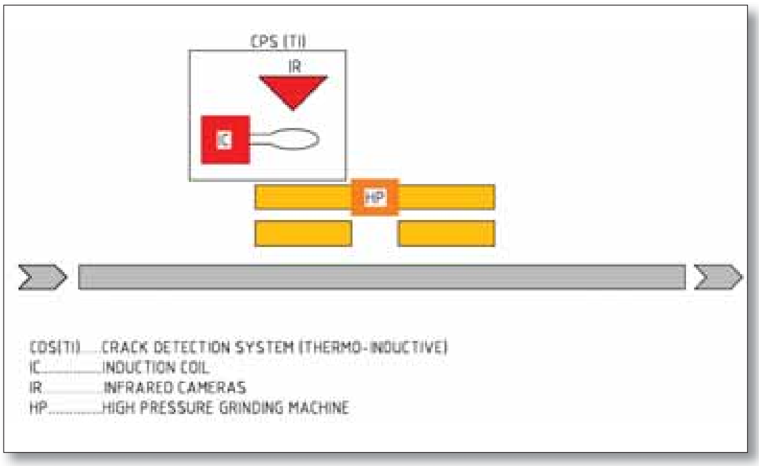

Fig 13 **Basic set-up for automated flaw grinding with thermo-inductive crack detection system attached to HP grinding machine and direct data transfer to grinding machine**

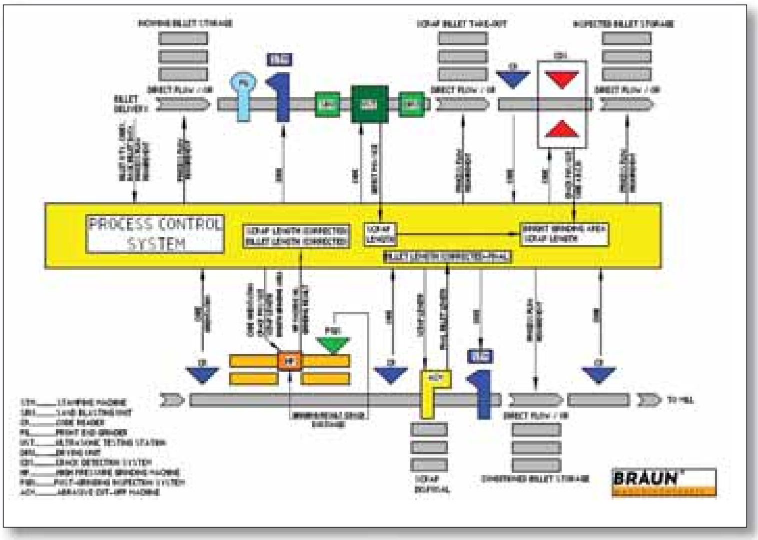

Fig 14 Basic set-up of a complex, integrated system for automated flaw grinding with crack detection system, 4 HP grinding machines, product identification and other equipment for material testing and conditioning

Fig 15 HP abrasive cut-off machine for cutting-off defective billet ends

thermo-inductive system. If a crack has not been removed completely, it can be reground immediately.

After inspecting and grinding of the first surface, the work piece is turned. Surface inspection and flaw grinding of the next surface is repeated in the same sequence as described above.

Whereas this set-up is relatively straightforward (only one infrared camera needed, no additional material handling equipment, paint marking and paint detection units or separate post-grinding inspection system needed) and also well suited for flat products (slabs), it is only economic for 'too large' throughput capacities, which can be achieved with one or two HP grinding machines (each grinding machine requires a crack detection system, time losses due to checking one side of the work piece after the other).

For large throughput capacities, a more complex set-up – such as the one described below – would be the better choice.

Example 3 Basic set-up for automated flaw grinding with several HP grinding machines, including permanent product identification, possibilities for material storage, data management and integration of additional equipment for material testing or treatment (see *Figure 14*).

For large production volumes and a broad product mix, the set-up of a fully automated, integrated facility for inspecting and conditioning of the various work pieces must be more complex and more sophisticated than the first and second examples described above.

Several grinding machines (each one equipped with a post-grinding inspection unit already described in the first example above, to allow an immediate regrinding if necessary) are required to reach the desired throughput capacities. Furthermore, for logistical reasons, possibilities must exist to put inspected work pieces in intermediate storage before they are ground as the need arises.

Perhaps it is also necessary to detect defects inside the work pieces and to cut out defective parts (including very deep cracks) of the work piece instead of having to reject the whole work piece as scrap. In this case, an abrasive cut-off machine, for example (see *Figure 15*), with scrap disposal and a material positioning system to stop the work piece in the right position for cutting out the defective part, can be integrated in the overall system.

For such a complex, integrated facility, an exact, permanent marking of the work piece that allows an automatic identification should be ensured in order to clearly allocate the data generated during the 'travel' of the work piece through the individual stations of the entire system to that work piece. Ideally, the work pieces are stamped when they are still hot (eg, directly after casting, forging or rolling). If the work pieces are stamped with an alpha-numeric code and/or a bar code, they can be identified not only visually, but also with an automatic code reader ahead of each individual step.

In addition to reliable product identification, a high-capacity material data tracking system with database is required. Data downloaded into the database at certain stations of the overall facility (eg, product identification, coordinates of detected surface cracks clearly dedicated to a certain work piece) must be uploaded at other stations (eg, the crack coordinates of a work piece after verifying the product identification of the work piece).

Marking the detected surface defects with paint as described in the first example above, is not absolutely necessary (and therefore also not shown in *Figure 14*). On the other hand, however, it might be useful to do such marking in order to minimise the looping of big data volumes through the complete system from station to station. This would also allow manual interference if the need arises such as in the case of malfunctions of the material data tracking system or – in extreme cases – also to manually grind the flaws with the HP (high-pressure) grinding machine. Arrangement of paint marking (after crack detection) and paint detection units are shown in *Figure 10*.

REFERENCE PROJECTS

Between 2014 and 2016, BRAUN completed two projects for HP billet grinding machines already prepared for a fully automated grinding of surface flaws as described above: one project for HYUNDAI Steel, Dangjing, Korea and one project for VOESTALPINE Stahl, Leoben-Donawitz, Austria.

In both cases, the overall solutions have been customised to the specific needs of the users. Even though BRAUN has not supplied the complete billet conditioning lines, BRAUN has supplied a large portion of the core equipment. In the case of HYUNDAI Steel this was four HP grinding machines together with all material handling equipment in the grinding area of the plant (see *Figure 16*), everything connected to the customer's higher-level plant control system.

In the case of VOESTALPINE Stahl, one HP grinding machine was supplied, already equipped with a code reading system (to read the alpha-numerical code at the front end of the billets for downloading the crack data detected earlier by the customer from a database into the PLC of the grinding machine), as well as and a post-grinding inspection system to allow an immediate re-grinding of not completely removed cracks, if necessary (see *Figure 17*).

CONCLUSIONS

Integrated solutions for fully automated detection and a fully automated grinding of surface flaws on metallic products are not only feasible, but can also be adapted to specific customer requirements. In light of the increasingly stringent quality requirements from the end users (eg, the automotive and aerospace industries), the producers of semi-finished metal products are forced to take measures to reliably achieve and guarantee the demanded product quality.

In light of this, it is easy to predict that the trend to integrated solutions for the detection and removal of material defects, including the recording and protocolling of all data will continue.

With BRAUN's HP grinding machine, one of the core components for such an integrated facility is availability. Furthermore, the company's specific know-how and experience in grinding, as well as the targeted R&D regarding flexible, integrated solutions for a fully automated grinding of semi-finished products, make BRAUN an ideal partner for the international steel and special metals industry. MS

Fig 16 **Four HP grinding machines at HYUNDAI Steel, Dangjing, Korea (grinding machines with material handling system in grinding area)**

Fig 17 **HP grinding machine at VOESTALPINE Stahl, Leoben-Donawitz, Austria (with material handling equipment at loading area)**

Norbert Asamer and Gerhard Richter are with BRAUN Maschinenfabrik GmbH, Vöcklabruck, Austria

CONTACT: g.richter@braun.at

REFERENCES

[1] G Richter and A Schmuckermayer, BRAUN Maschinenfabrik GmbH, 'Innovative concepts for grinding of large-scale round parts', in *Millennium Steel 2008*

[2] G Richter, BRAUN Maschinenfabrik GmbH, R Ofner and E Fauster, ex vatron GmbH, 'Integrated solutions for a fully automated grinding of surface flaws on semi-finished products', in *Millenium Steel 2009* and *SEAISI Quarterly Journal 2010*, 39(3)

[3] B Oswald-Tranta, 'Thermoinductive investigations of magnetic materials for surface cracks', in *QIRT Journal* 1(1), p33, 2004