Automated grinding of surface flaws on semi-finished products

High pressure grinding has proven to be the optimum technology for removing surface defects on semi-finished products prior to further processing. BRAUN’s multi-functional grinding machines provide fully automated full-surface, corner and flaw grinding of a range of products. Automated grinding of surface flaws requires accurate detection, positioning of the defects and transmission of these data to the control system beforehand. BRAUN, partly in cooperation with specialised manufacturers of surface inspection and product identification systems, has developed such flexible solutions.

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BASIC PRODUCTION REQUIREMENTS
The surface of cast, forged or rolled products may contain cracks, inclusions and scale and, depending on steel grade and application, these imperfections may need to be removed prior to further processing. High pressure grinding has proven to be the most reliable and effective technology to achieve fault-free surfaces. Thanks to its reliability, high capacity and flexible applicability, but also due 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-section)
- 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 regard to surface roughness, grinding depth, brightness of the surface, etc, it is necessary to select the proper wheel specification (ie, type and size of the 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 such 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 grinding pressures as high as possible 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.

Peripheral speed of the grinding wheel To achieve long service life, grind quality and, to a lesser extent, the achievable removal rate, 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 (262ft/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, 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 a higher carbon content, this could lead to discolorations and local hardening of the surface. 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 1998/99. 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 of starting diameter of 635mm (25in) (see Figure 4).

Throughout the design of this facility BRAUN used the latest technical advances available at that time and to develop a substantially improved design. 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 different materials, including many alloys sensitive to surface cracks and surface decarburisation. Furthermore, it was beneficial that BRAUN took the operational experiences already made by the customer into account during the 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 by BRAUN in this way represents a new, innovative grinding concept. This concept fully and perfectly meets the above-mentioned key criteria [1].

Essentially, the design is a table grinding machine. This means that the actual grinding unit is anchored to the foundations 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:

- A significantly higher stability of the grinding unit
Excellent and consistent visibility for the operator who sits in a soundproof control booth

Substantially better encapsulation of the grinding area and controlled removal of the swarf and dust

Other key design features of BRAUN’s machines are:

- Grinding drive with powerful, frequency-controlled motor allows for maintaining a constant peripheral speed of the grinding wheel independent from the wheel diameter
- Special wheel wear compensation system by measuring the actual grinding wheel diameter and automatic adjustment of peripheral speed
- Highly efficient and flexible design of the grinding head with weight-saving yet robust construction – allows grinding pressures up to 1,400kg (3,100lbs), exact adherence to the pre-selected grinding pressure and uniform material removal – even if the surface of the work piece is rough or curved (see Figures 5 and 6)
- 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 5)
- 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 7)
- 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 8)

METHODS FOR FULLY AUTOMATED GRINDING OF PARTIAL SURFACE FLAWS

While BRAUN’s 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 an automated grinding of partial surface defects, the machine needs to know where the flaws are. Therefore, the surface defects must be detected prior to the grinding process. The conventional way of detecting surface cracks and removing them by only grinding the
were introduced in 2009 [2]. Additional, more flexible solutions, not strictly bound to a specific type of crack detection system, have been developed since then. In the following, three basic solutions are described:

Example 1: basic set-up for automated flaw grinding without direct data transfer from crack detection system (see Figure 9)

Crack detection can be done in the conventional way, i.e., manually (PT inspection) or automatically. In the latter case, either a magnaflux testing system or a thermo-inductive system can be utilised. 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 HP grinding machine. If a crack has not been removed completely, it can be reground immediately.

In Figure 9, the schematic of a thermo-inductive system is shown (in lieu of other crack detection systems) because it features several advantages, such as the following [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 10). During the run through the induction coil, the material is inductively heated for a short period. 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

Fig 9 Basic set-up for automated flaw grinding with thermo-inductive crack detection system and 4 HP grinding machines, without direct data transfer from crack detection system to grinding machine

Fig 10 Schematic of principal components for the thermo-inductive testing of squared billets
(source: former VATRON GmbH, Leoben, Austria)
observed with the infrared cameras. Finally, the material defects are detected by means of digital image processing algorithms [2] (see Figure 11).

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

Example 2: Basic set-up for automated flaw grinding with thermo-inductive crack detection and direct data transfer (see Figure 12)

In this case, a thermo-inductive system is directly mounted on a vertically adjustable mechanism at the outside of the grinding cabin, 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, but the top surface of the work piece is also simultaneously inspected by the crack detection system. The coordinates of the detected surface defects are then directly transferred to the grinding machine PLC. Subsequently the determined surface areas of the work piece are ground. A re-inspection of the ground areas can also be done with the thermo-inductive system and, 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 units) and also well suitable for flat products (slabs), it is only economic for not 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 really large throughput capacities, a more complex set-up – such as example 3 below – is 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 13)

For high production volumes (e.g., 1Mt/yr or more) 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 sophisticated than that described in examples 1 and 2. Several grinding machines (each equipped with a post-grinding inspection unit already described in example 1 to allow an immediate regrinding if necessary) are required to reach the desired throughput capacities. Furthermore, due to logistic reasons, possibilities must exist to put inspected work pieces in an intermediate storage before they are ground as needed.

If it is also desired to detect defects inside the work pieces and, according to the positions of these internal defects or of too deep surface cracks, to cut out defective parts of the work piece instead of having to reject the whole work piece as scrap. For this purpose an abrasive cut-off machine (see Figure 14), 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 still in hot condition (e.g., directly after casting, forging or rolling).
FINISHING PROCESSES

If the work pieces are stamped with an alpha-numeric code and a bar code as well, they can be identified not only visually, but also with an automatic bar code reader ahead of each individual step (see Figure 15).

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 example 1, is not absolutely necessary (and therefore not shown in Figure 13). On the other hand, 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 intervention if the need arises (eg, in case of malfunctions of the material data tracking system) or – in extreme cases – to manually grind the flaws with the HP grinding machine. Arrangement of paint marking and paint detection units are as shown in Figure 9.

CONCLUSIONS

Integrated solutions for fully automated detection and fully automated grinding of surface flaws on metallic products are not only feasible, but can also be adapted to the specific customer requirements. In light of the increasingly stringent quality requirements from the end users (eg, 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 the removal of material defects, including the recording and protocolling of all data, will further continue.

With BRAUN’s HP grinding machine, one of the core components for such an integrated facility is available. 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 industry.

REFERENCES


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