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LATEST DEVELOPMENTS FOR SLAB SURFACE CONDITIONING: INNOVATION IN SLAB GRINDING[1]

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Abstract
The purpose of this paper is to illustrate the latest developments in slab surface grinding process. Thanks to the technologies described it is possible to reach the target to feed the downstream rolling mill with starting material free from defects, together with the optimal performances in terms of efficiency, productivity, manpower requirements and environmental impact, for any steel grade.
Key words: Slab conditioning; Inspection; Surface quality; High power grinding.

MAIS RECENTES DESENVOLVIMENTOS PARA CONDICIONAMENTO SUPERFICIAL DE PLACAS: INOVAÇÃO EM ESMERILHAMENTO DE PLACAS

Resumo
Este trabalho tem como objetivo ilustrar os recentes desenvolvimentos em condicionamento superficial de placas. Devido a tecnologia descrita é possível entregar a laminação um material de partida livre de defeitos, agregado com um desempenho otimizado em termos de eficiência, produtividade, disponibilidade de mão-de-obra e impacto ambiental para qualquer grau de aço.
Palavras-chave: Condicionamento de placas; Inspeção; Qualidade superficial; Esmerilhamento.

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1 INTRODUCTION

Total quality control in the steel making process is of ever increasing importance, due to increasingly stringent quality and performance requirements of the finished steel products in the automotive, aerospace, engineering and similar industries.
Even with the most modern casting plants, to certify 100% of the steel slabs and billets before feeding into the rolling mill, grinding plants are an essential tool to ensure a top quality rolled product. The key issues facing steel producers are the efficiency, productivity, manpower requirements and environmental performance of such plants.
The purpose of this paper is to illustrate the very latest characteristics of a modern slab surface conditioning plant which incorporating the following technology:

- The E cube (e^3) grinding process for a better surface roughness and lower grinding wheel consumption;
- the intelligrind inspection process for automatic slab grinding;
- the supergrinder high power grinding system with 630 KW (approx. 860 hp) spindle power for ultra high production rates.

The paper will also report the latest results of slab conditioning plants incorporating such State of the Art features.

2 E3 GRINDING PROCESS

By means of old DCMK grinding machines it was possible to operate on the slab either at 90° or at 45° angle of the grinding wheel respect to the slab direction. The configuration is changed directly from the operator pulpit by means of hydraulic cylinder and hydraulic clamps.
The two configurations have the following utilisation:

- 90° set up angle was utilised for surface finishing and for corner grinding. Its advantages are a very high surface quality and a longer grinding wheel life due to a more constant consumption of that wheel. Its disadvantage is a lower productivity due to the necessary over grinding (Figure 1);
- 45° operation was utilised for rough conditioning. Its advantage is a high productivity but has the disadvantages of higher grinding wheel consumption due to the uneven utilisation of the wheel and a lower surface quality (Figure 2).

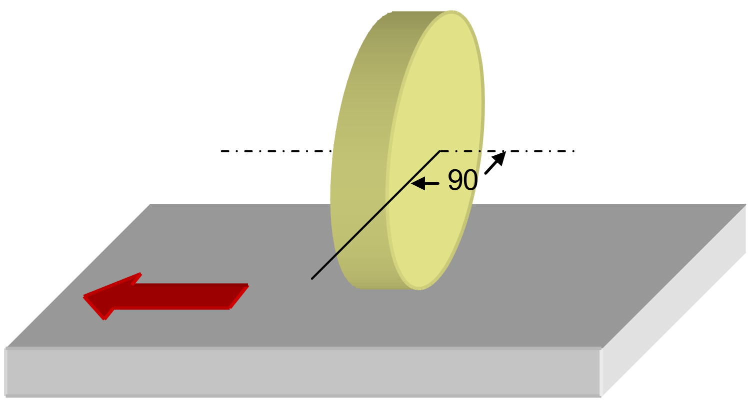

Figure 1. 90° set up angle.

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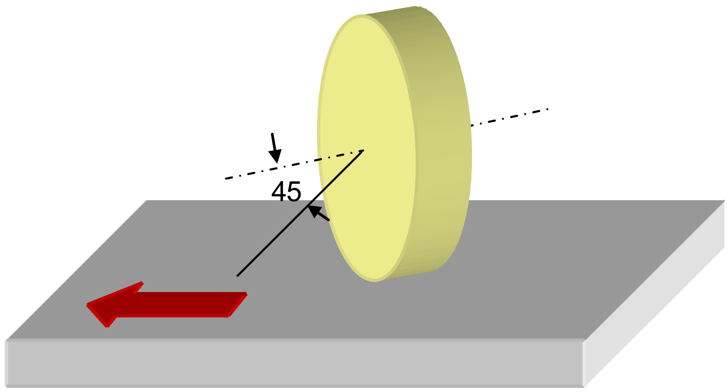

Figure 2. 45° set up angle.

Operating on the slab with the 90° set up angle we have a lower productivity because part of the motor power is spent to grind an unwanted area of material. This phenomenon is called over-grinding (Figure 3).

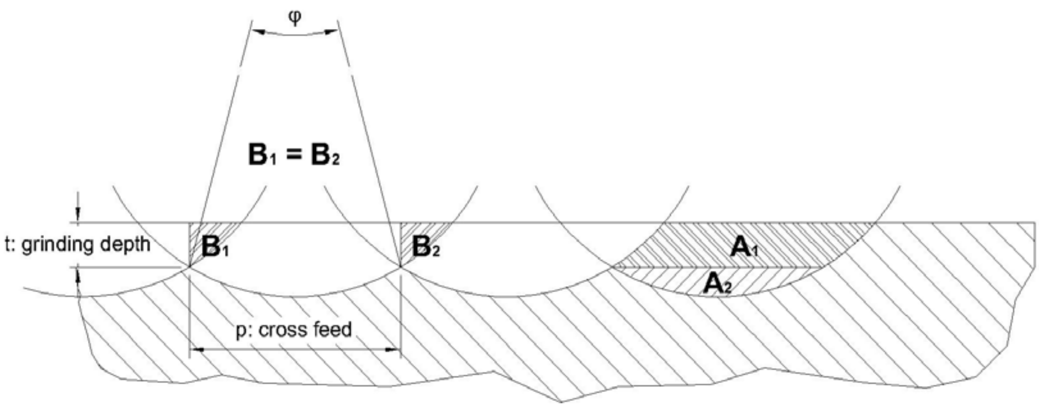

Figure 3. Over-grinding scheme.

The useful grinding is the grinding contact area that is needed to remove the required amount of material:

$$A_1 = p \times t$$

Where:

- A1 = useful grinding;
- p = cross feed;
- t = grinding depth.

The over-grinding reduces the productivity and increase waste of material, and it is easily calculated with the following formula:

$$A_2 = p\left(\frac{p^2}{6D} + \frac{p^4}{32D^3}\right)$$

Where:

- A2 = over-grinding;
- p = cross feed;
- D = grinding wheel diameter.

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Operating on the slab with the 45° set up angle we avoid any over-grinding area increasing the productivity of the grinding machine and increasing also the yield of the line (Figure 4).

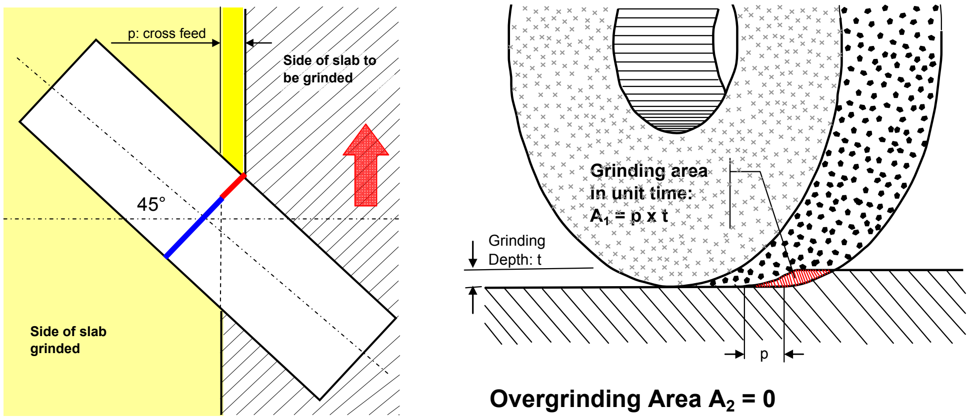

Figure 4. 45° grinding process.

In that case we avoid the over-grinding phenomenon because the grinding wheel has a flat contact area with the slab surface. With this set up only a portion of the grinding wheel surface is utilized due to the cross feed and it is fast consuming, reaching higher wheel consumption up to 30% respect 90° set up. The remaining surface is not taking out material, but it is hitting the slab surface already conditioned damaging it and getting worse the surface quality reaching a 30% to 40% higher Ra (Figure 5).

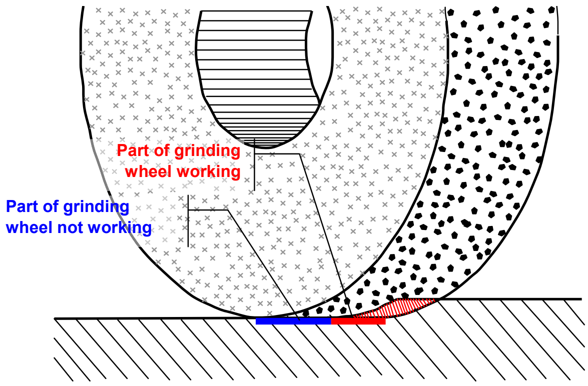

Figure 5. 45° disadvantage.

For this reason DCMK developed a new machine, either in terms of mechanical solution but also with a new automation function, with the target to find an optimum grinding angle where it is possible to have maximum productivity (no over-grinding) and at the same time reduce wheel consumption and have better surface finishing.
So DCMK developed a grinding machine which can operate at any grinding angle. The optimum grinding angle, α0, (Figure 6) will be calculated by the automation system according to the characteristics of the equipment utilised and of the slab to be processed (Table 1).

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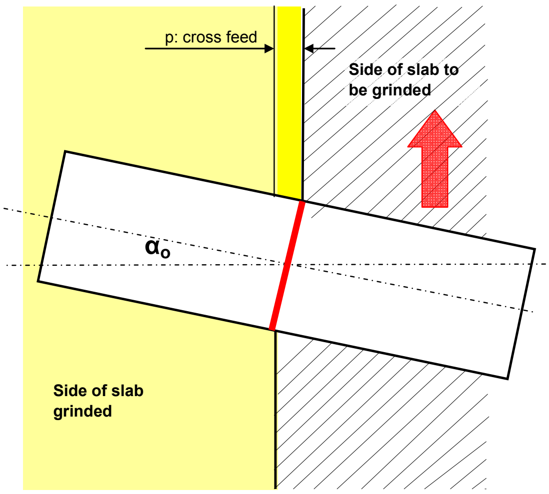

Figure 6. Optimum grinding angle.

Table 1. Example of angle calculation

Machine motor power	Steel grade		Grinding depth	Grinding wheel set-up	Grinding speed	Cross feed	Optimum angle
kW	-		mm	mm x n.	m/s	mm	°
315	Carbon	cold	2	105 x 2	0.6	32	82
		hot	2	105 x 2	0.6	55	75
	3xx	cold	2	150 x 1	0.5	26	80
		hot	2	150 x 1	0.6	47	72
	4xx	cold	2	150 x 1	0.5	22	82
		hot	2	150 x 1	0.5	43	74
630	Carbon	cold	2	125 x 2	0.6	63	76
		hot	2	125 x 2	0.8	83	71
	3xx	cold	2	125 x 2	0.5	53	78
		hot	2	125 x 2	0.7	81	71
	4xx	cold	2	125 x 2	0.5	44	80
		hot	2	125 x 2	0.6	72	74

Key points of this new configuration have been already tested in several plants in cooperation with SlipNaxos. The results are better than expected one and when the full system will be implemented the following advantages will be obtained:

- same grinding capacity of 45° configuration;
- reduced grinding wheel consumption of 20% respect to 45° configuration;
- improved surface roughness of at least 20 µm respect to 45° configuration.

3 INTELLIGRIND, THE ON LINE SURFACE INSPECTION SYSTEM

This is a main concern for many final users. To simplify checking operations we developed the On-line Inspection System (Intelligrind). Through this, the operator will check the slab's surface and send the automation system the coordinates of any residual defect directly from the pulpit. Then, grinding will be done entirely in automatic mode, even in spot grinding mode. This allows a single operator to manage a complete

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line of two or more machines directly from the pulpit, which also reduces downtime for inspections.
An On-Line Inspection System is an image acquisition unit which is mounted at entry side of the grinding machine (Figure 7).
It records in a high definition (HD) monitor the image of the slab traveling on the slabs grinding table which passes below the image acquisition system.
The slab image section recorded and transferred to the first monitor is approx. 2,150 mm width and 1,300 mm length.
When the complete slab is recorded the full slab length is shown in a second monitor where the operator by means of a image zooming system, is able to highlight the defected area and sign by means of the available mouse, the 2 coordinates of the defect, area that will be automatically transferred to the machine PLC for being subsequently grinded.
As soon as all the defects are acquired by the system and the data acquisition is completed, the machine can proceed of grinding and condition the indicated areas.

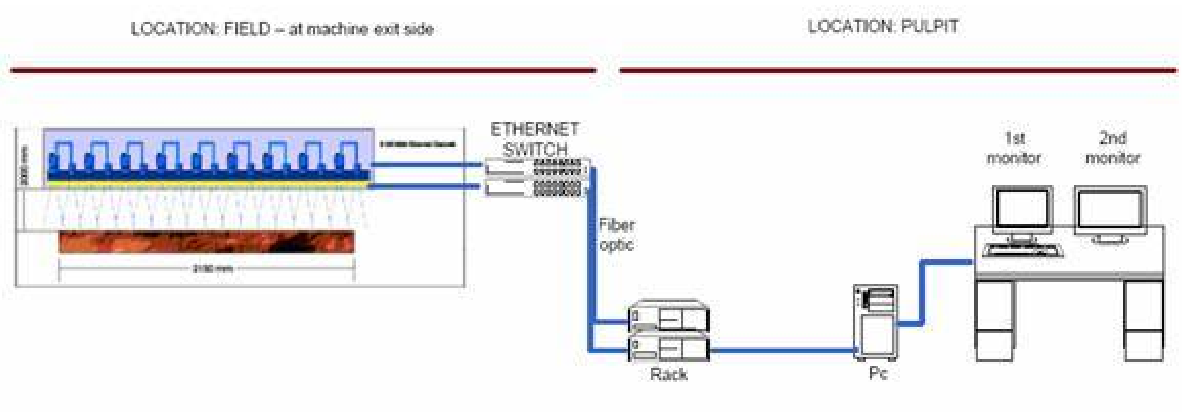

Figure 7. On Line Inspection System.

Each image acquisition system is composed of a set of high definition cameras mounted crossways on the slabs transporting area at entry and exit side of the grinding machine (Figure 8).
The HD cameras has a resolution of 1,504 pixels in width and 960 pixels in height (length of slab) as required to guarantee a resolution of approx. 0.3 mm on the monitor.
Internally of the image acquisition there is an Ethernet switch with a local electrical board with an exit signal in fiber optic GigaEthernet, a feeder stabilized 24Vcc for image acquisition, a local switchboard, control of the air or liquid cooling system, the vision windows cleaning by means of a compressed air system.
The image acquisition area lighting system is composed of an independent system from the image acquisition, and it is connected with an industrial type cabling system for feeding and control.
The image acquisition system to be able to cover a slab width of approx. 2,150 mm shall be mounted at approx. 2,000 mm over the slab surface.
At image acquisition system entry side it is mounted a photocell for measuring the start and finish of the slab in process.

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Each couple of image acquisition systems are conveyed trough a “college blanket” in optical fiber to the related control pulpit. The fiber optical channel works at a speed of 1 Gbyte/second, and such speed is required to guarantee a frame rate required for the system.

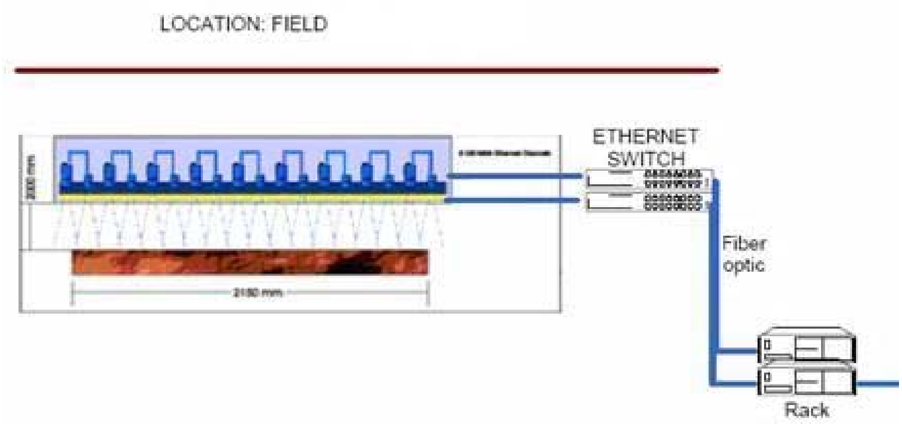

Figure 8. Image acquisition system.

Internally of the pulpit it is installed a rack 19” type board with the PC’s for image acquisition and processing, the Gigabit Ethernet switch for data acquisition and the supervisory and display PC (Figure 9).
The HMI in the pulpit is composed of 2 monitors of 26”, a desk with keyboard and a mouse to insert the working parameters.
The 26” monitors have a maximum resolution of 1,920 pixels x 1,200 pixels, and with such resolution it is possible to generate various operational modes for entering the working parameters.
On the first monitor it is visualized the complete slab and are also highlighted the areas where the operator has located a defect(s) to be grinded, while in this display are shown also the operational and configuration parameters.
On the second monitor located closed on the side, are shown the areas of interest and herein we are listing some possible display modes that can result useful to the operator during his analysis of such defects.
Mode 1 (Normal Mode): display of a slab section having 2,150 mm width and 600 mm length. In this operational mode the system shows the full width of the material with a resolution of 0.85 mm x 0.85 mm a pixel.
Mode 2 (Zoom Mode): display area 380 mm x 240 mm. In this operational mode the system shows the material with the maximum resolution obtaining a theoretical resolution of 0.2 mm x 0.2 mm a pixel.
Thanks to the image acquisition software and supervision it will be possible to switch from vision in station 1 to the station 2 in a simple and intuitive way.

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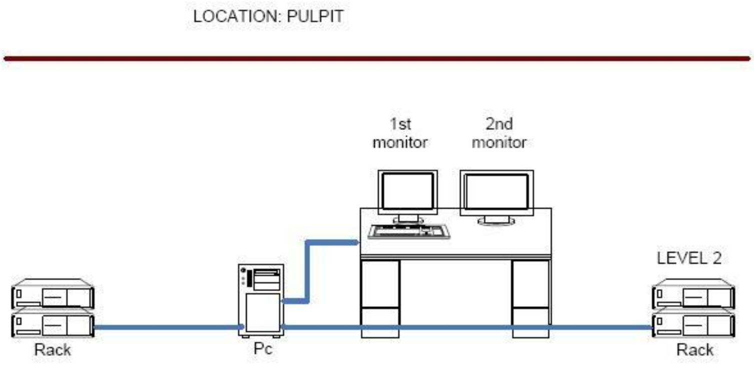

Figure 9. Control Pulpit.

The Operating software is able to control up to 2 monitors, one for the control of the data parameters and the visualization of the complete material and the second for highlighting the details and for the defects identification.
Taking into consideration that the material during the image acquisition travels at 500 mm/second speed and considering that at such speed it results impossible for the operator to see the surface defects, the system turns to a "programmable slow motion preview" which will allow to simulate a virtual forward speed of the material at a variable speed based on the parameters much suitable to the operator.
Then thanks to the display and vision of the complete material surface, the operator is able to move through the complete acquired image surface area and verify in the zoomed image the presence of defects. Then using suitable instrumentation and procedures for data entry (mouse, etc.) the operator can enter the defect(s) and any required parameter for defect grinding and conditioning.
Based on the fact that the system allows saving various parameters and working procedures over system interchangeable files, it will be possible to generate operational profiles for the various operators servicing the grinding line.
The system allows also generating of reports, saving of such reports and the creation of paper reports on the printer.

4 SUPER GRINDERS

For both Stainless Steel and Carbon Steel producers there is the need of higher production plants with just two (2) machines only: the first for the top face and the second after turning the slab, for the bottom face of the slab, thus limiting the space and equipment requirements.
Specially in the carbon steel sector a grinding plant in-line with a modern slab grinding machine shall be able to grind at very high production rates to condition in continuous the "as cast" hot slabs, with only two (2) machines and therefore with a lower investment and transformation cost.
With this target DCMK has developed the Super Grinders, a new set of grinding machines which incorporates a high capacity grinding spindle driven with a motor having double power than the standard 315 KW motor.

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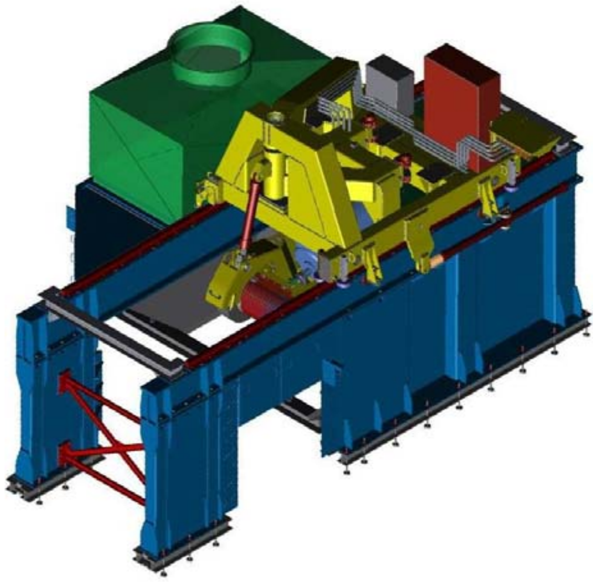

Figure 10. Supergrinder assembly.

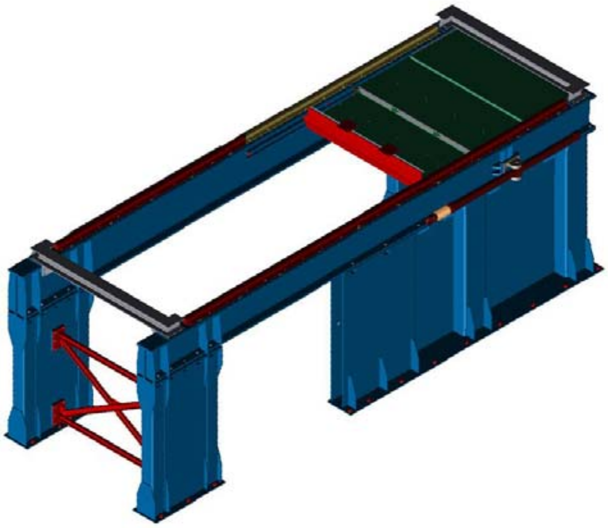

Figure 11. Supporting structure.

The DCMK Super Grinders are high power grinding machines incorporating a gear type grinding spindle air-oil lubricated, driven by an AC motor having 630 KW power, v.v.v.f. controlled (Figure 10).
The grinding machine supporting structure has been redesigned and made heavier in order to keep under control the heavy forces involved to avoid abnormal vibrations which could have a negative affect on the of the surface of the product being conditioned (Figure 11).
The grinding spindle has been redesigned with the installation of larger bearings and an improved air-oil lubrication system. The spindle is mounted on a heavy duty pendulum, housing the spindle with its gear driving assembly, coupling and motor. The pendulum is pivoted at one side while at the other side it is connected to the hydraulic cylinder that provides the grinding pressure required for the grinding process (Figure 12).

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For the hot grinding operations the pendulum and spindle assembly are shielded with a set of heavy duty water cooled panels and provided with high temperature water cooled hoses to withstand the severe working conditions and obtain a long life of the spindle and of the machine components.

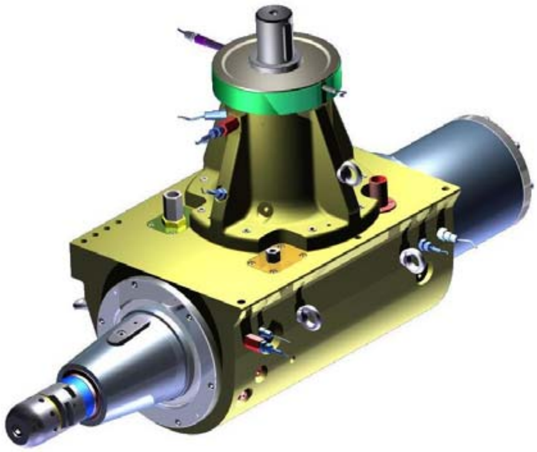

Figure 12. Spindle assembly.

Figure 13. Hub and flange arrangement.

The grinding spindle houses 2 grinding wheels having a diameter of 915 mm and 150 mm thickness each, mounted side by side. Both grinding wheels are mounted on the standard DCMK hub and flange arrangement designed for a semi-automatic grinding wheels changing method (Figure 13).
The grinding plant handling system is the same as the one used in the DCMK standard grinding plant, which has proven to be highly reliable, works in fully automatic mode, it is made of heavy duty and long life components and requires very little maintenance (Figure 14).
Such characteristics represents the main parameters to be taken in chief consideration for high efficiency grinding plants used also for the continuous, in-line operations.

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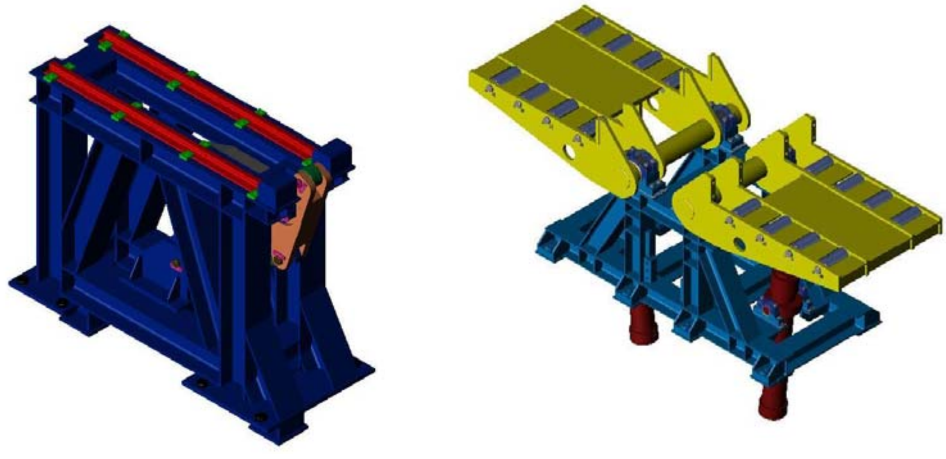

Figure 14. Examples of handling equipment.

The grinding capacity of a plant is directly related to the Material Removal Rate (MRR) and is measured in Kg of steel removed per kWh of the grinding motor installed (Kg/kWh). The standard Material Removal Rate (MRR) for Cold to Worm (up to 500°C) are: for the Stainless Steels grades 2.3 Kg/kWh – 3 Kg/kWh; and for the Carbon Steel grades 3 kg/kWh to 4 kg/kWh; while for Hot Grinding or from 600°C to above 900°C it is as high as 3.5 kg/kWh - 5 Kg/kWh for Stainless Steel grade, and 6.5 Kg/kWh - 7 Kg/kWh for Carbon Steel grades.

A plant of this nature with 630 KW main grinder motor power considering skin grinding of stainless steel hot slabs with an average weight of 30 tons and 1,6 meters wide, 12 meter length, removing 2 mm depth each face, it has a grinding capacity of approx. 142 TPH.

Should we consider to grind hot slabs of carbon steel grades, and a combination of skin grinding (50%) and pattern grinding (50%), the same plant have a capacity of approx. 225 TPH (Table 2).

Table 2. Example of productivity calculation

GRINDING PLANTS FOR CONDITIONING OF SLABS 1 – Slab characteristics: Dimensions: 1,600 mm x 200 mm x 12 meters Weight: 30 metric tons 2 – Grinding Depth: 2 mm (1 pass) 3 – Plant grinding time: 7,600 hrs./year 4 – N° of Grinding Machines in Plant: 2	**PRODUCTIVITY OF STANDARD GRINDERS (315 kW)**	**PRODUCTIVITY OF SUPER GRINDERS (630 kW)**
COLD GRINDING OF STAINLESS STEEL (50% 3xx Series + 50% 4xx Series / Skin Grinding)	390.000 TPY	690.000 TPY (+77%)
HOT GRINDING OF STAINLESS STEEL (50% 3xx Series + 50% 4xx Series / Skin Grinding)	580.000 TPY	980.000 TPY (+69 %)
HOT GRINDING OF STAINLESS STEEL (50% 3xx + 50% 4xx Series / 50% Skin + 50% pattern grinding)	790.000 TPY	1.130.000 TPY (+43 %)
COLD GRINDING OF CARBON STEEL (50% Skin grinding – 50% pattern grinding)	690.000 TPY	1.160.000 TPY (+68 %)
HOT GRINDING OF CARBON STEEL (50% Skin grinding – 50% pattern grinding)	1.020.000 TPY	1.550.000 TPY (+51 %)

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5 CONCLUSIONS

Quality stainless and carbon steel products for the engineering, chemical, automotive and avionic industry requires total quality products, surface conditioned and free of any defect. They shall be produced efficiently, with the lowest investment and at high production rates.
Grinding as a process competing with the cold or hot scarfing operations, presents several advantages.
DCMK grinding machines and integrated grinding plants presently installed are high performance plants, which allows to grind hot slabs at casting temperatures over 900°C.
In order to fulfill such needs, DCMK has developed these new developments in slab surface inspection and conditioning technology. E cube grinding process to decrease consumption of grinding wheel and increasing productivity of the grinding plant and slab quality surface; Intelligrind, the On Line Inspection System to simplify and to help inspection of the slab surface; Super Grinders which houses a double power motor to provide the extra grinding capacity, without incrementing the number of grinding machines, therefore keeping to the minimum the size of the grinding plant and the investment required.