DRESSING STRATEGY FOR VITRIFIED CBN WHEELS USING ACOUSTIC MONITORING

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Abstract. *This paper presents a dressing strategy for vitrified CBN wheels for crankshaft grinding using acoustic monitoring. In order to maintain the active surface roughness of the wheel, the depth of cut in the dressing stroke is extremely narrow, including typical values of 2 or 4 μm in the wheel radius. The dressing system must ensure that the programmed depth of cut is reached in all dressing profile, avoiding thermal deviations and detecting wheel and/or dresser unbalancing. Using an electroplated diamond disc, a cross-axis dressing configuration was applied in order to dress the whole wheel profile (side, radius and face). A preliminary set point of predefined points in the diamond disc perimeter is performed using acoustic emission and they are used to calculate the path to be described by the wheel. An acoustic mapping of the wheel surface is obtained during the dressing. The image, which is displayed in the HMI interface of the open architecture CNC, is used to evaluate the dressing stroke, allowing the detection of unbalancing and other dressing problems. With the aid of this technique, full contact profile dressing was obtained in the first dressing stroke of 2 μm even with the machine not thermally stabilized.*

Keywords**:** *grinding wheel, CBN, dressing, acoustic emission, monitoring*

1. Introduction

The grinding performance of vitrified CBN wheels is strongly dependent on the dressing operation, considering that their truing and conditioning are performed in a single operation. In most of the cases, the rotary diamond discs are used driven by electric units. Truing operation with metal bonded diamond rotary truer is usually used as a method to obtain high efficiency and high accuracy of wheel shape (Takagi and Liu, 1996). In order to maintain the active surface roughness of the wheel, the depth of cut in the dressing stroke is extremely narrow when compared to the conventional abrasives dressing, including typical values of 2 or 4 μm in the wheel radius. The dressing system must ensure that the programmed depth of cut is reached in all dressing profile. Thermal deviations and dresser and/or wheel unbalancing lead to unsatisfactory dressing operation with lack of contact during dressing or undesired active surface in the wheel.

This paper presents a dressing strategy for vitrified CBN wheels using acoustic monitoring. The dressing process of a profiled CBN wheel for crankshaft grinding is monitored by the acoustic mapping of the wheel surface integrated on the HMI interface of an open architecture CNC. Using an electroplated diamond disc, a cross-axis dressing configuration was applied in order to dress the whole wheel profile (side, radius and face). The most important features of dressing strategy and the obtained results are presented.

2. CBN wheels dressing

The major advantage that vitrified bonds offer over other bonds systems is the ability to be dressed automatically without any subsequent conditioning of the surface. This is achieved by a combination of the brittle nature of the bond and the ability to introduce porosity. Together this allows the structure to be crushed with resulting preferential loss of bond and exposure of the abrasive (Hitchiner, 1998). Vitrified CBN wheels are dressed, almost exclusively, using diamond on the surface of a rotating wheel. In dressing, the CBN and diamond grains impact at high speed where the relative fracture characteristics of the abrasives are of equal or greater importance. To survive in a dresser the diamond must have both high hardness and toughness.

Terminology in dressing of CBN wheels is rife with confusion and misunderstanding. Descriptions of the process can include “dressing”, “truing”, “conditioning”, “sharpening” and “cleaning” all given different or interchanged meanings by different authors. According to Hitchiner (1998), the following meanings can be applied to each appropriate term.

a) **Truing** - creating a round wheel concentric to the axis of wheel rotation, and generating, if necessary, a particular profile on the wheel face.
b) **Conditioning** - preferential removal of bond from around the abrasive grits.
c) **Dressing** - truing the wheel and conditioning the surface sufficient for the wheel to cut at the required performance level.

Virtually all dressing processes for production grinding with CBN require the use of a rotating metal disc termed either a "dresser" or "truer" or "form roll" depending on application and containing diamond in a given matrix The configuration of the CBN grinding wheel and diamond dresser can take many forms (Hitchiner, 1998):

a) **Uni-axial traverse dressing** of straight or simple form profiles **using narrow disc or cup dressers**
b) **Cross-axis traverse dressing** of profiles using narrow disc dressers
c) **Uni-axial traverse dressing using profiled form dressers**
d) **Plunge form dressing** using a reverse plated or sintered diamond "form roll"

There are essentially three choices of dresser spindle available: electric, hydraulic and air. Electric spindles are by far the most popular and flexible, either as a VF direct drive or belt driven. They can provide a reasonably high torque and variable speed capability. Hydraulic dressers are less expensive than electric dressers and provide a high torque but they also generate heat and create thermal expansion errors. Since this expansion occurs primarily along the dresser axis their use should be limited to disc dressers only. Air spindles are the least expensive of dresser styles. They run cool and at high rotation but have very poor torque values. Their use is limited to internal grinders using small diameter cups.

Among the dresser configurations presented above, the uni-axial dressing of straight forms is the most common configuration. The details are presented in Fig. (1).

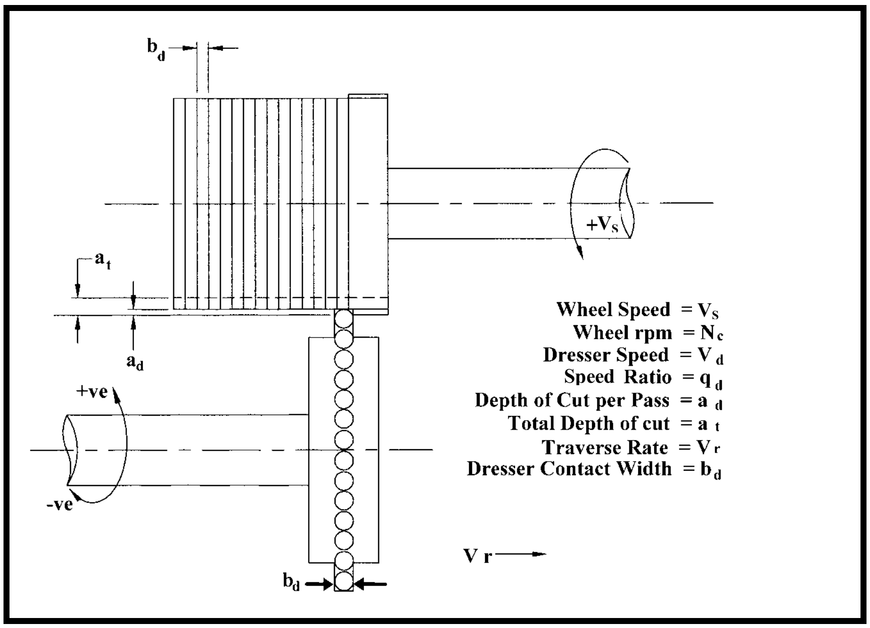


Figure 1 – Uni-axil dressing configuration (Hitchiner, 1998)

The geometric relation between the diamond grains on the disc and the CBN grains in the wheel was determined by the ratio between the disc and the wheel, namely truing speed ratio (qd) (Takagi and Lui, 1996), defined by the Eq. (1):

$$q_d = v_d / v_s \quad (1)$$

A positive speed ratio leads to a more effective crushing action. For different speed ratios it is possible to obtain different degrees of grain fracture, ranging from micro-fracture to macro-fracture (Ishikawa and Kumar, 1991). Micro-fracture leads to a high surface abrasive concentration and therefore a higher wheel life but also relatively high grinding forces; macro-fracture with its lower surface concentration of sharper abrasives led to lower wheel life but lower grinding energy. As the crush ratio was increased from +0.2 to +0.8 the level of macro-fracture increased dramatically to dominate the process accompanied by increased bond loss. According to Takagi and Liu (1996), the roughness increases with higher q_d (+), as observed in the Fig. (2).

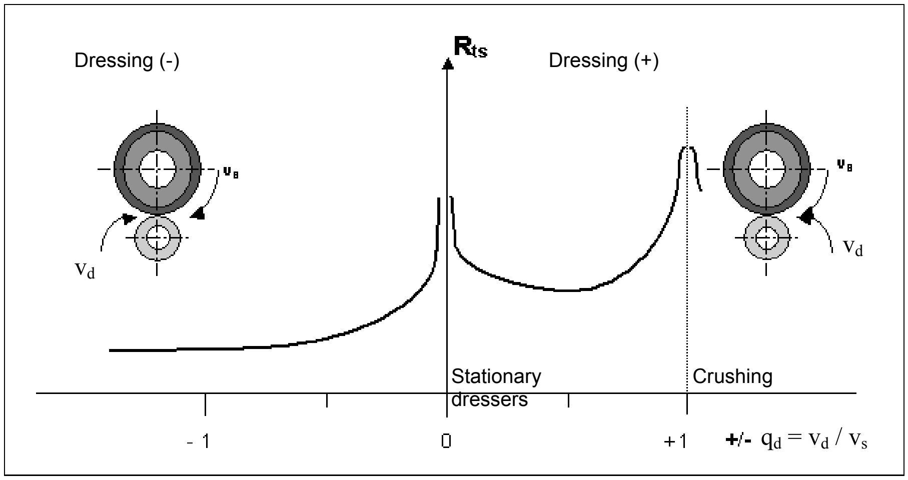


Figure 2 – Roughness for different q_d (adapted from Takagi and Liu, 1996)

According to Takagi and Liu (1996), when speed ratio is small, the collision takes place at the tangential direction to CBN grains. A shearing action force act on CBN grains then friction wear and small crushing were produced on CBN grains. On the other hand, when truing speed-ratio is over 0.8 (+) the collision between diamond grains and CBN take place at the radial direction of the CBN grains. Then a compressive force act on the CBN grains, large scale crushing is produced on them. Normal truing force increases remarkably and sharp grain cutting edges are formed. As observed in Fig. (2), sharp wheel face is formed at the region where speed-ratio is close to 1.0 (+). However, at such speed ratio, the normal truing forces are rather high, which could result in deterioration of geometrical accuracy of trued wheel (Takagi et all, 1990). Also, excessive crushing action may cause acceleration of wheel wear. According to the results obtained by Takagi et all (1990), optimum speed ratio for CBN wheel seems to be about 0.8 (+) because of not so high value of normal truing force and satisfactory low value of grinding forces. If finer surface roughness were required for finishing grinding, good results would be expected at speed ratio less than 0.6 (+).

The cross-axis configuration is presented in Fig. (3).

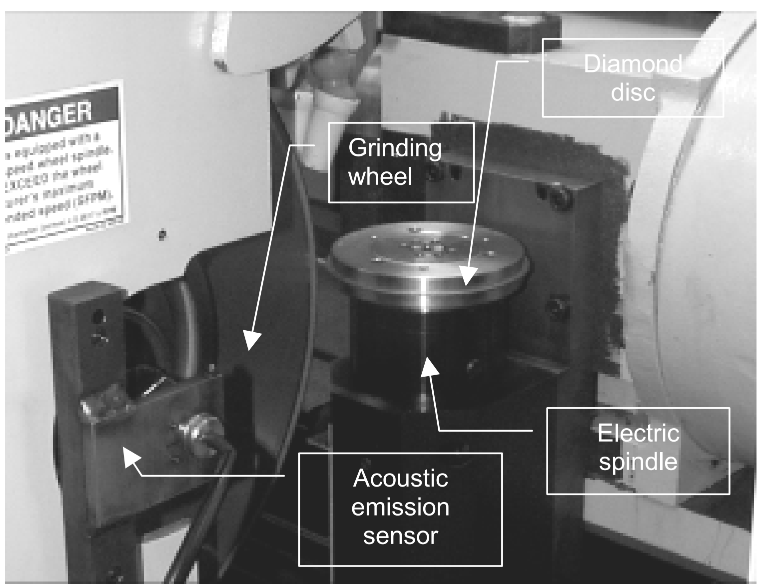


Figure 3 – Weldon high speed grinder equipped with cross-axis USI VF14 electric dresser for cylindrical contour grinding of shaft diameters and shoulders (Hitchiner, 1998).

The dress action produces only shear so is never as effective as uni-axial dressing with a high $+v_s$ crush ratio. The traverse rate is dependent on dresser diameter Dd and depth of cut a_d. Simple geometry gives an optimum traverse rate of (Eq. (2)):

$V_r = 1.5\ N_s\ (D_d\ .\ a_d).1/2$ (2)

Hence the process is, to a first approximation, independent of CBN or diamond grit size, or dresser rpm. Dressers developed for uni-axial dressing also work well for cross-axis dressing, particularly the thin impregnated diamond disc design. The most exciting successes with cross-axis dressing to date have come from CNC profile grinding for applications such as punch grinding and high speed contour grinding. An example is shown in Fig. (3), which is a photograph of a Weldon grinder tooled for cylindrical profile grinding at 130m/s. The dresser is a VF electric spindle. The acoustic sensor is mounted in the wheel head and monitors dressing and grinding process, as well as adding crash protection. The dresser touches off on the outside diameter and face at the start of the dress sequence to determine wheel position in x and z planes and compensate for thermal movement. Cross-axis dressing is the most cost effective method of profile dressing where the contour allows its use. One additional benefit is it gives clearance to dress profiles of over 180°. This allows, for example, back angle relief to be dressed on the sides of a 1A1R wheel when high speed contour grinding of shaft diameters with shoulders (Hitchiner, 1998).

The surface of any grinding wheel is significantly modified compared to its bulk structure. The dressing process fractures and removes abrasives particles and bond to reduce the surface concentration of both. Yokogawa was the first to describe this affected layer which he termed "Tsukidashiryo", also known as "Active Surface Roughness", and can vary in depth from a few microns to over thirty (Yonekura and Yokogawa, 1983; Mindek, 1992). For most medium to high stock removal applications, once grinding begins the abrasive metal chips will wear the bond preferentially and further increase the affected depth (Fig. 4). This is accompanied by a drop in grinding forces and a rise in surface finish and is most striking for the first few parts after dress.

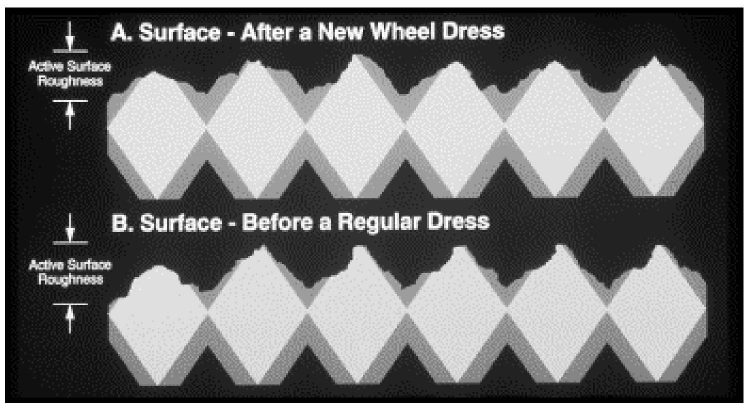


Figure 4 – Active surface roughness

The rapid drop in power can be reduced by optimization of dress parameters but rarely if ever eliminated. Its effect on weak stiffness systems such as internal grinding has had a profound affect on grinder control systems. When dressing a conventional wheel any comparable drop in force is too rapid to have any effect on the part quality and the dress infeed amount is such that most or the entire layer affected by the grinding is removed and a fresh surface layer created each new dress. Not so for CBN where the dress depth of cut is only 3um or less for the reasons discussed above. A brand new wheel straight after the first dress will have its shallowest affected depth, which will increase with grinding. (If a wheel is likely to cause burn it will occur on the first part ground). For the second dress if too little material is removed the parts/dress achieved will be reduced whereas if too much is removed the surface returns to that of a new wheel. In general a balance has to be struck dependent on the particular grinding process in question. What is clear is that not only is the dress depth of cut per pass important governed by the fracture characteristics of the abrasive but also the total depth of cut is also critical governed by the active surface roughness.

4. Test methodology

In order to obtain a full profile dressing operation of a vitrified CBN wheel for crankshaft grinding, a cross-axis configuration was adopted. The setup is presented in Fig. (5a) and (5b):

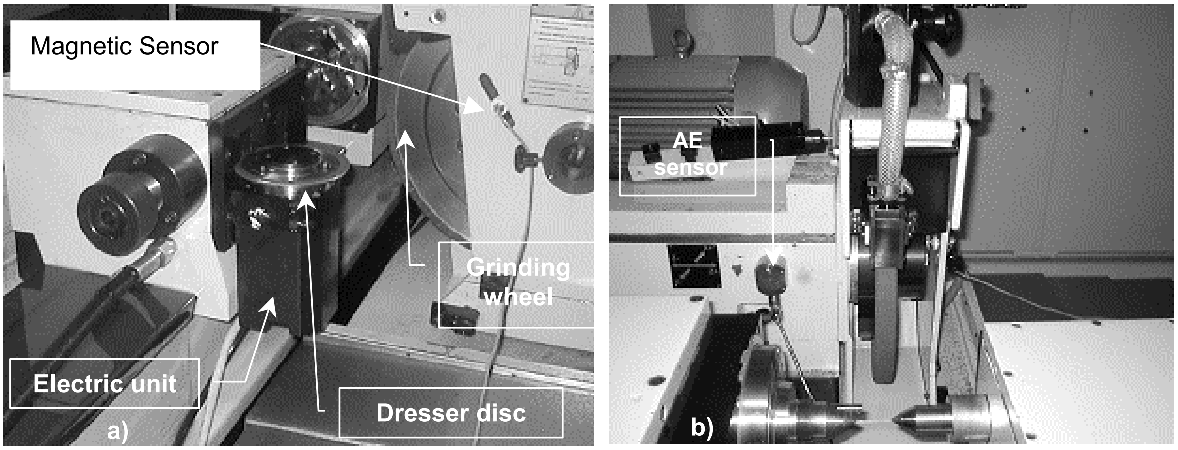


Figure 5 a) Internal side view of the ZEMA G800 HS grinding machine with the cross-axis dressing system in detail. b) Internal front view of the grinding machine, indicating the AE sensor positioning.

In this cross axis setup the rotation centers of the dresser and the grinding are perpendicular (Fig. 5a). The dresser is fixed in the backside of the tailstock. An electroplated diamond dresser disc with random distribution of the grains was used. The maximum dresser rpm is 4760. Considering the disc diameter equal to 129 mm, the maximum dresser peripheral velocity was equal to 32 m/s. The wheel diameter was equal to 400 mm. The maximum cutting speed was 100 m/s. The purposed monitoring system elements requires the installation of the acoustic mapping system developed by Oliveira et all (2000). A magnetic sensor used to synchronize the acoustic emission signals acquisition and the wheel rotation was installed in the wheel guard (Fig. 5a). A pre-amplified acoustic emission sensor was installed in the wheel headstock placed nearby the wheel shaft hydrostatic bearing (Fig. 5b). The AE signals are processed by the signal conditioner, which was installed in the operator panel (Fig. 6a).

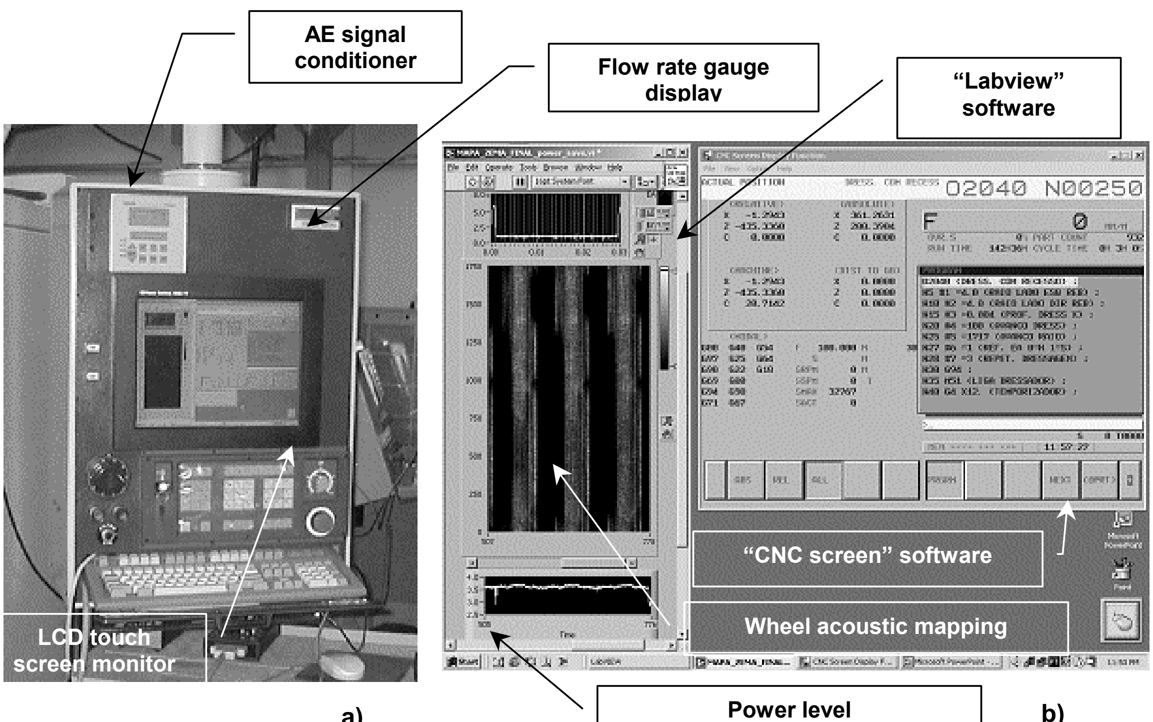


Figure 6 a) Front view of operator's panel of an open architecture grinding machine. b) Details of the control panel screen. On the left, the acoustic mapping software. On the right, the machine control software, both running simultaneously in a Windows 2000 Professional platform.

The Fig. (6) presents the integration between the machine operational system and the installed acoustic mapping system. An important feature of this grinding machine is the open architecture configuration, which allows the fully integration between the proposed system and the machine control. Third-party software can be easily integrated with this CNC generation. In this machine, the PC-CNC communication is performed installing in the PC-main board (this

PC is installed inside the operator panel, Fig. 6a) a PCI communication board. Using an optical fiber cable, the CNC is connected to the PC with a baud rate equal to 25MBps. All the controlling sensor actions are performed in the PC environment. The core tasks are still performed in the PMC. In Fig. (6b), the screen of the human-machine interface (HMI) is presented. The operational system of the PC is the Windows 2000 Professional. On the right, one can see the software CNC screen, which is responsible for the machine controlling (program running, axis jogging, etc.). It runs simultaneously with the Labview software, in which the routine for the acoustic mapping generation was developed. As an example, during the dressing operation, it is possible to control de machine and generate the acoustic mapping of the wheel surface and monitoring the grinding power level, simultaneously. Besides, all the PC features are available, such as Internet connection and other Windows and third-party software facilities.

A strategy for dressing the entire wheel profile is present in Fig. (7), in which five dressing regions were defined. The trajectory described by the grinding wheel during the dressing is also presented. All the profile is dressed combining linear movements and counterclockwise circular interpolation.

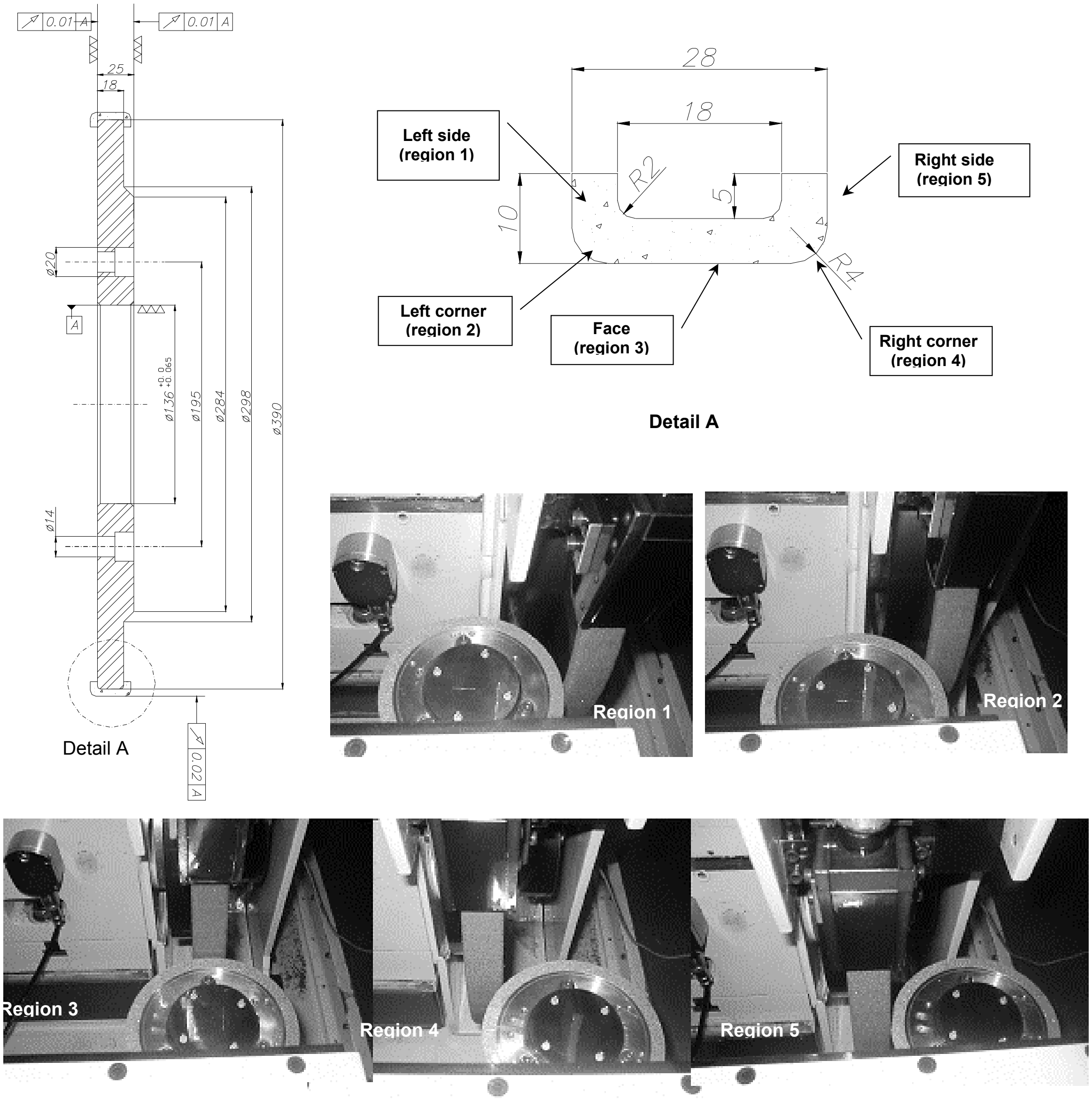


Figure 7 – Dressing regions of the profiled CBN grinding wheel

The CNC program developed to perform the dressing operation consists on linear displacements to dress the sidewalls (right and left ones) and the wheel face (regions 1, 5 and 3, respectively). A counterclockwise interpolation is performed to dress the 4-mm radius (regions 2 and 4).

One of the most important features of this dressing methodology is the acoustic emission set point of predefined coordinates in the dress disc. This step has two basic functions: eliminates the machine thermal deviation influence in the preset coordinates and collect data to calculate the trajectory to be described by the grinding wheel during the dressing. The predefined coordinates are the positions: X#500 (dresser top position X – wheel face midpoint in the X axis); Z#501 (dresser right position Z – wheel left sidewall midpoint in the Z axis); Z#502 (dresser left position Z – wheel right sidewall midpoint in the Z axis). The other parameters involved are: #518 (dresser disc diameter); #517 (wheel width); #527 (CBN segment height). These parameters are presented in Fig. (8).

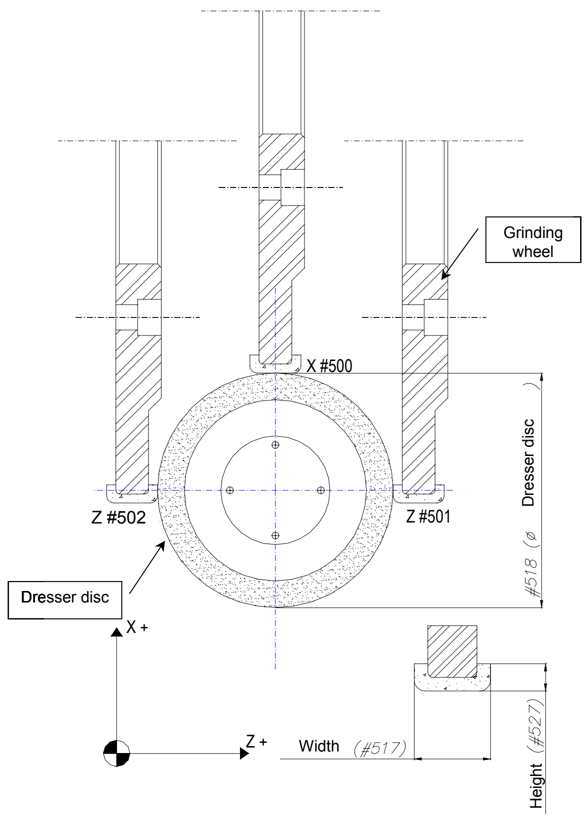


Figure 8 – Dressing coordinates and parameters

After the installation of the dressing unit, a manual set point of the dresser was performed, collecting the coordinates X#500, Z#501 e Z#502. The wheel width (#517) and the wheel segment height (#527) were measured and the values were stored in the CNC memory. In the sequence, the first acoustic set point was performed. The procedure for collecting the coordinates is as follow.

With the wheel and the dresser running, using a skip function, the wheel trajectory is programmed to touch the disc in the three preset coordinates, in the following sequence (Z#501, X#500, Z#502). The wheel feed rate is G0 in the nearby of the preset coordinates. When the wheel approaches the coordinates (80 – 100 μm remain to the contact occurs), the feed rate is commuted to the touch-programmed feed rate, defined by the machine operator. A skip function G31 replaces the linear interpolation function G01 in the wheel linear approach. The contact between the dresser and the wheel is detected monitoring the instantaneous RMS acoustic emission level. When the wheel touches the dresser, the signal level trespass the predefined level limit, the trigger is actuated and the acoustic emission signal processing unit generates a 24V-signal in a high-priority CNC input (skip signal). At this moment, the CNC executes the next block of programming, which contains the line command for coordinate capture when the skip signal was received (X skip coordinate for #500, and Z skip coordinate for #501 and #502). The coordinate values X#500, Z#501 and Z#502 are updated. Based on these coordinates, the disc diameter #518 is calculated by the Eq. (3):

$$\#518 = Z\#501 - Z\#502 - \#517 \quad (3)$$

The set up procedure can be executed before each dressing procedure. It is a subroutine (O2041) in the dressing program. In the dressing program (O2040), the face and the sidewalls are dressed using linear displacements G01 with programmed feed rates. The corners are dressed using counterclockwise interpolation, dressing a radius of 4 mm. Due to the different velocities in the disc center and in the contact point dresser-wheel it is necessary to correct the corner feed rate. This correction is presented in the Fig. 9.

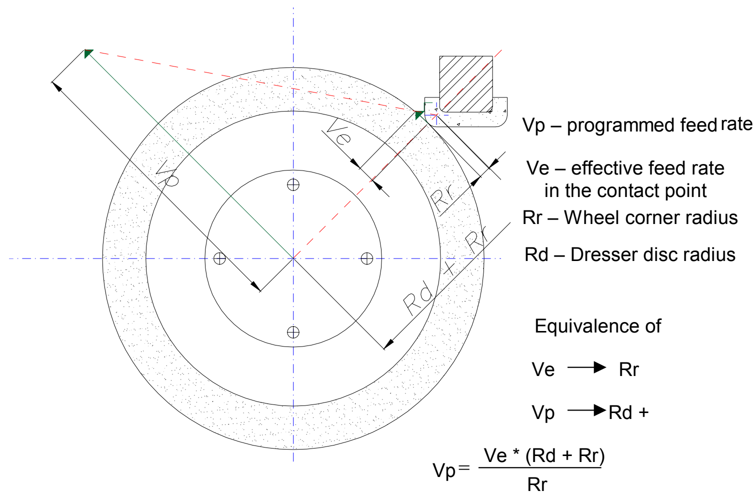


Figure 9 – Velocity corrections

5. Results and discussion

Dressing tests were performed in order to test the system reliability. With the grinding machine just started a set point operation was performed. Table 1 presents some results of the preset coordinates captured by the acoustic emission touch set point, for a touch feed rate of 2 mm/min. The thermal deviations of the dresser disc and the machine can be corrected using this technique.

Table 1 – Coordinates captured values for the dresser set point F=2 mm/min

X#500	Z#501	Z#502
359,4465	358,9981	201,1627
359,4504	359,9991	201,1626

A dressing operation using the acoustic mapping of the wheel surface was performed. The dressing infeed was equal to 2 μm along all the wheel profile (v_s = 45 m/s; v_d = 28 m/s). In this first test, the dressing feed rate in the corners was not compensated. The effective feed rate in the contact point was equal to 6 mm/min, considered a programmed feed rate of 100 mm/min. The sidewalls were dressed with feed rate of 100mm/min. This first dressing is presented in Fig. (10a). In this Fig. (10a.) it is possible to verify that the area that corresponds to the corner dressing is larger than the one of the wall dressing. The two regions have the approximately the same linear distance to be dressed, the programmed fee rate is equal to both regions, but the effective dressing velocity is much slower in the corner dressing. Using the corrected feed rate as proposed in Fig. 9, the programmed feed rate must be equal to 1717 mm/min. The velocity in the contact point during the corner dressing was corrected, leading to a constant feed rate in the entire dresser-wheel contact trajectory. The new acoustic map is presented in Fig. (10b).

The system can also be used to detect dressing problems, as detected in Fig. (10a). As presented on Fig. 11, after mounted and balanced, the wheel periphery must run concentrically. The system was used to determine the number of strokes to ensure that the entire wheel profile is being dressed with the programmed depth of cut. The number of stroke can be more safety defined, considering that the acoustic mapping is being generating simultaneously with the performed dressing operation. The machine operator can detect, using the system, the exact moment, in which the entire profile was dressed and the dressing operation can be stopped.

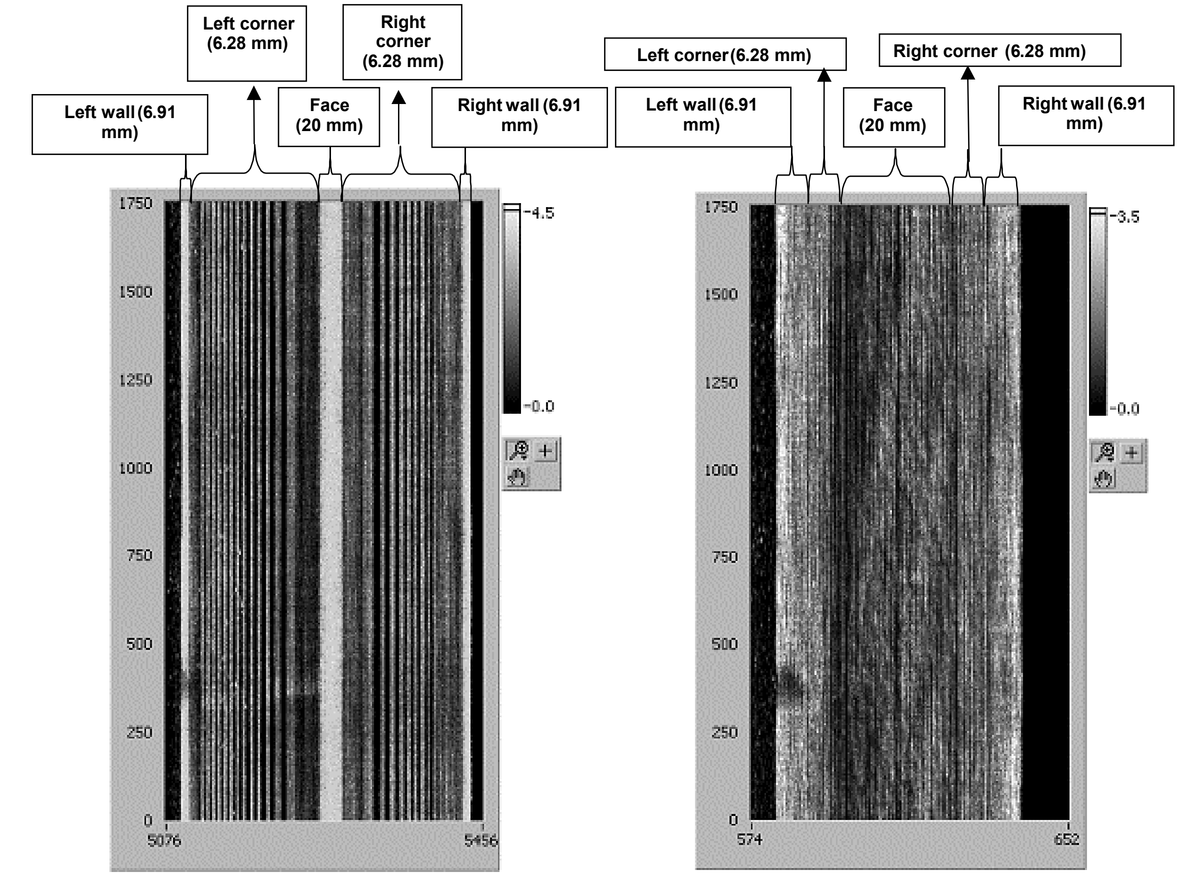
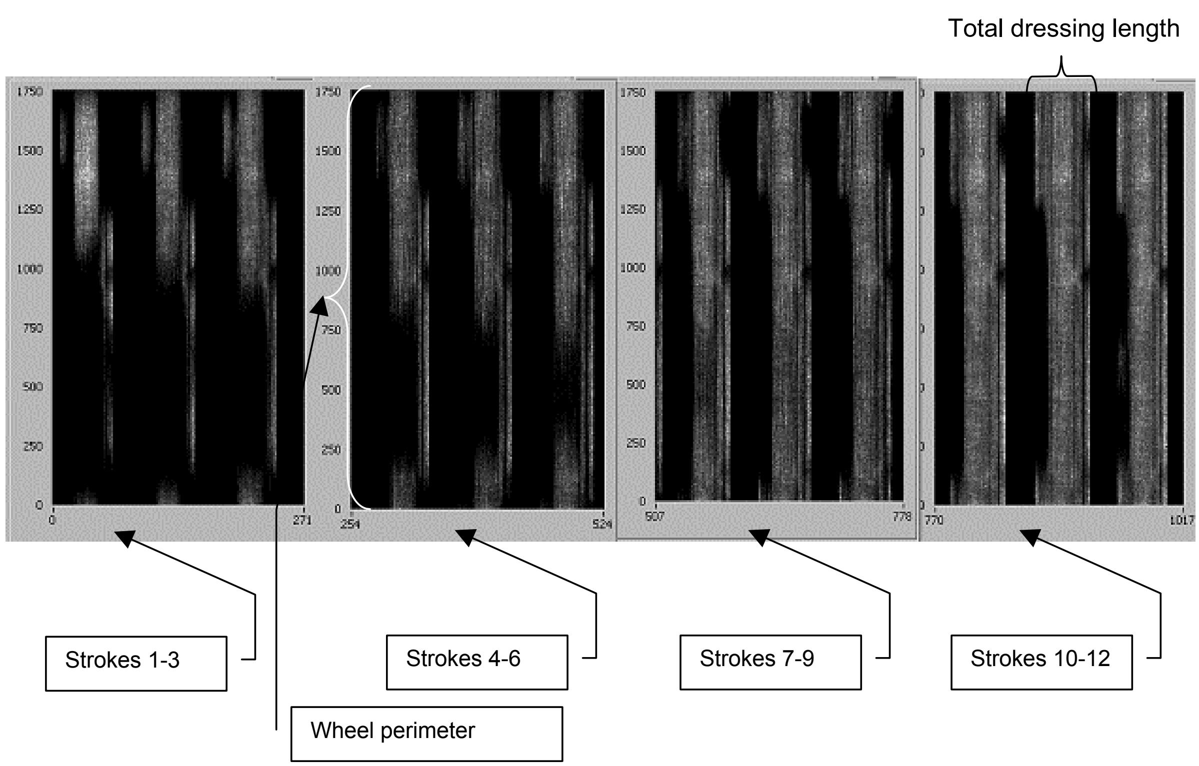


Figure 10. – Acoustic Mapping of the dresser operation with feed rate of 100 mm/min in the face and in the sidewalls a) corner feed rate not compensated. b) corner feed rate after compensation.



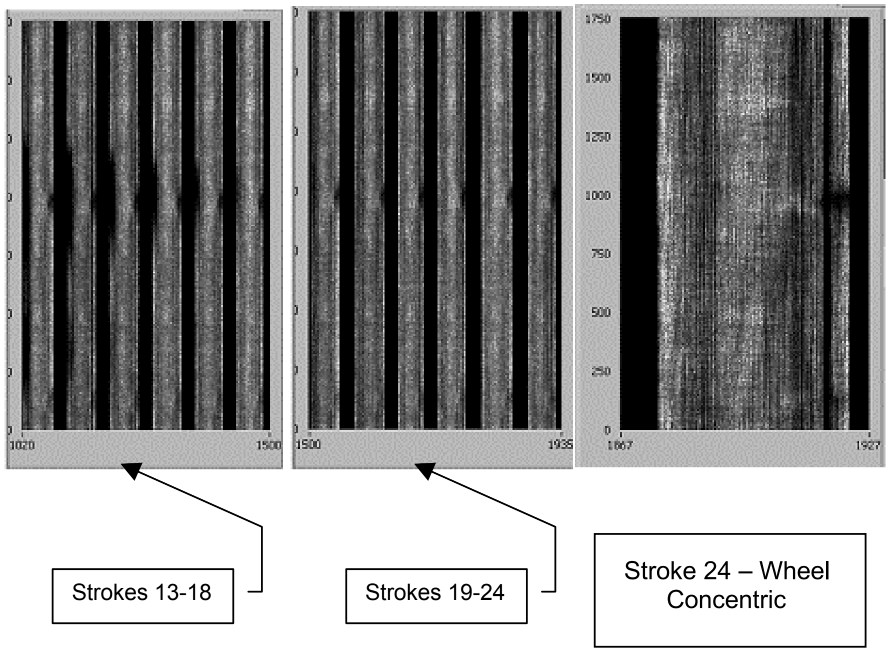


Figure 11. – Evolution of the dressing procedure of a run-out wheel (depth of dressing – 2 μm).

6. Conclusions

According to the results obtained in this research, the authors conclude that:

The proposed dressing system is able to dress profiled grinding wheels and to prevent machine thermal deviations errors in dressing operation. The cross-axis configuration allows dressing profiles up to 180 degrees.

Full-contact dressing operations can be performed even with machine just started and dressing decisions can be taken based on system results simultaneously to dressing operation.

7. Acknowledgments

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