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ADVANCES IN PART TEXTURING BY GRINDING

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Abstract. *The production of engineered surfaces to increase part functional performance is being widely used in manufacturing. Reduction of friction and wear are target outputs when designing such surfaces. Once the desired pattern is defined, the next challenge is how to economically fabricate it. Parts texturing by grinding using patterned wheels is a very promising technology that can overcome the drawbacks of laser machining, etching and lithography, due to low inventory cost and process modifications and short machining time. The wheel is patterned during dressing by dynamically changing the dressing depth according to the wheel angular position. Patterns are transferred to the workpiece during grinding by selecting integer speed ratios between wheel and workpiece. The paper presents the description of the developed technology as well as the most significant obtained results.*

Keywords: *grinding, texturing, patterned wheel*

1. INTRODUCTION

In the scenario of modern manufacturing, with the current demand for machining with the minimum consumption of resources and in a sustainable way, the performance in service of the machined component can be highly influenced by the obtained surface. It can play an important role in terms of energy and signal transmission by defining the mechanisms and the kinematics involved in those exchange phenomena in a micro and nano scale (Bruzzone *et al.*, 2008). For example, tribological properties are highly influenced by the degree of interaction between two surfaces, leading to different results of friction, wear and or lubricant conditions with a direct impact on energy consumption. Many other examples of the surface importance can be derived, considering other fields of applications such as: electronics, optics, biology, among others.

The research on structured surfaces in a micro and nano scale is being a very active topic (Bruzzone *et al.*, 2008, Denkena *et al.*, 2008; Li *et al.*, 2011; Mals *et al.*, 2010; Oliveira *et al.*, 2010; Ramsden *et al.*, 2007; Brinksmeier *et al.*, 2010; Kong and Cheung 2011; Denkena *et al.*, 2010a; Denkena *et al.*, 2010b), including the development of novel/improved manufacturing methods along with the understanding of role played by the proposed functional structure and major application fields.

Bruzzone *et al.*, 2008, propose the categorization below for the manufacturing methods based on the physical principles involved. For all listed manufacturing methods the great current challenges are to economically produce the features in volume scale with a certain degree of flexibility.

a) *Adding material*: chemical and physical process that add material and creates small raised areas of relief by adding material, e.g., chemical conversion coatings and focused ion beam for wear resistant patterns, respectively
b) *Removing material*: features are created removing material and generating small areas of depressions by high temperature (ex.: laser methods), chemical etching (ex.: chemical texturing) and mechanical (ex.: CNC ultrasonic machining, micro cutting, grinding, etc.)
c) *Moving material*: Surface structure changed by plastic deformation and material redistribution by mechanical (ex.: shot blasting) or chemical action (ex.: molecular migration);
d) *Self-forming*: texture formed by regions at the part of different resistance to wear. Processes include: localized diffusion (ex.: printing+heating) and combination of hard and soft phases (ex.: embedding of soft phases);

Considering the removing material manufacturing methods, different techniques are being used to tailor structured surfaces. Laser machining has been used with success to produce structures in powertrain components targeting to reduce friction and wear by providing micro lubrication (Schubert *et al.*, 2011; Yi and Dang-Sheng, 2008; Anderssson *et al.*, 2007); to promote micromechanical interlock (Byskov-Nielsen and Balling, 2009). Major drawbacks of the technique are related with the fine tuning of laser process parameters (pulse energy, pulse frequency, cool off between pulses) to avoid material recast and sealing of the hole and to control structure dimensions and to achieve an economical production rate. Oscillator-only micromachining using femtosecond lasers arose as an alternative to overcome those quality issues (Gattass, 2006; Rizvi, 2003).

To apply particular geometric patterns or pockets in large areas, normal cutting operations, such as turning and milling are being used, as well as abrasive processes such as grinding. Using both processes a large flexibility and high precision have been achieved (Denkena *et al.*, 2010a).

Considering the potential applications for structured surfaces produced by machining processes, the paper investigates the advances in part texturing by grinding, describing the available techniques and the obtained results.

2. PARTS TEXTURING BY GRINDING

Producing textured parts by grinding basically consists on transferring preexisting patterns from the wheel to the part during grinding. The way the textures are imprint on the wheel surface allows grouping the developed techniques in two main categories: the ones who use a grinding wheel with custom-made grain arrangements, with controlled grain protrusion and grit spacing. The other group consists on grinding wheels with their bond specially conditioned during dressing. The first group involves the development of a custom-made grinding wheel, with the associated challenges in controlling the grain positioning and protrusion during wheel manufacturing. Single layer wheels with superabrasive grains are the main examples of so-called “engineered grinding tools – ETG” (Pinto *et al.*, 2008). Those wheels were developed aiming to increase the material removal rate, or to generate a particular grinding pattern on the workpiece surface, as in polishing operations. Prediction of the resulting pattern, derived from the kinematic interaction between each grain and the workpiece is a key in this type of application. Modifications in the grain arrangement are made upon the desired pattern output and kinematic limitations. As a result, kinematic simulation of the grinding process is required for that prediction, allowing output results in terms of grinding force dynamics, workpiece surface roughness and chip cross section area and the theoretical scratching pattern (Aurich and Kirsch, 2012). That allows, for example, the determination of the spatial distribution of glossiness over a polished surface (Souza *et al.*, 2007).

The second group of producing textured parts includes the technique that allows the special conditioning of the bond, developed by Oliveira *et al.*, 2010. The technique consists on dynamically change the radial infeed movement of a dressing tool to imprint patterns on the wheel surface. The dressing tool movement is performed by adding a high-frequency actuator into the regular dressing setup. Patterns can be defined by the operator by selecting a proper computer code, in which the dressing tool controlled excitation will be synchronized with the wheel speed to produce the pre-selected desired pattern. Acoustic emission mapping of the wheel surface is used as a quality control tool for wheel pattern imprint. Schematic of the setup is presented in Figure 1 (Oliveira *et al.*, 2010).

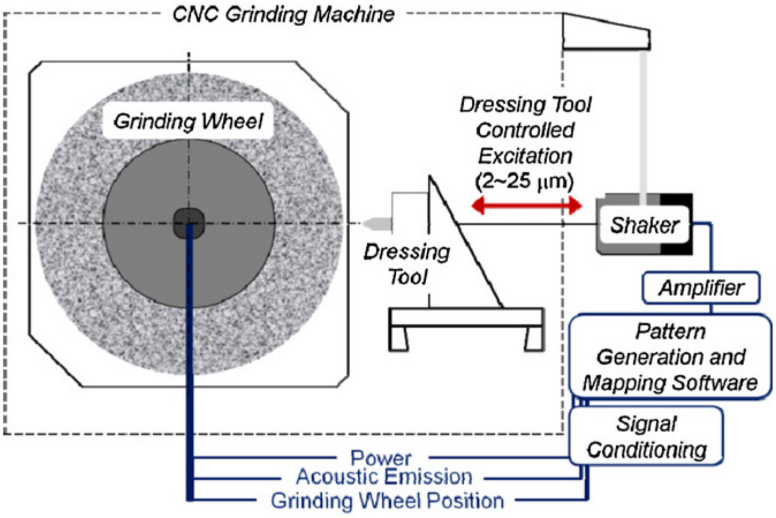


Figure 1 – Proposed method to structure grinding wheels (Oliveira *et al.*, 2010)

The patterns on the grinding wheel are transferred to the workpiece during the final grinding operation by selecting an integer speed ratio between wheel and workpiece. Wheel patterns are scaled up when transferred to the workpiece during grinding by selecting proper values of integer speed ratio or by increasing changing the number of features imprint during the dressing operation. The full description of the applied methodology can be found in Oliveira *et al.*, 2010. Examples of the results obtained are in Figure 2.

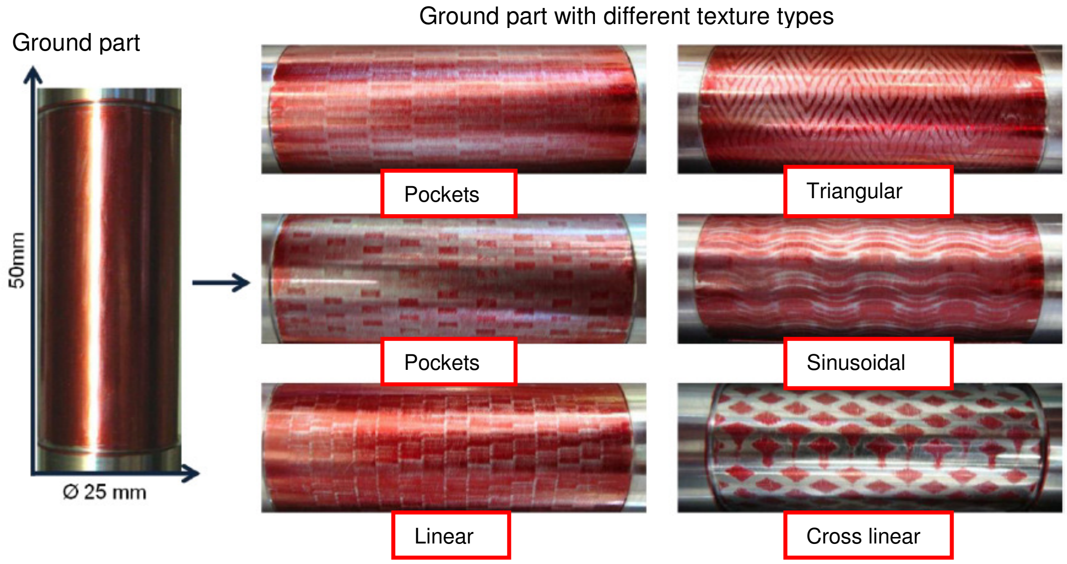


Figure 2 – Examples of parts textured by grinding using the proposed technique (Bottene, 2012)

In the aforementioned technique, by selecting a non-integer value of speed ratio, textured wheels can be used to increase the wheel performance in terms of grinding power with a slight variation in the surface quality of the workpiece (Oliveira *et al.*, 2010). In that situation, there's no pattern transfer to the workpiece. Wheel can be textured to promote a more efficient cutting, with an additional wheel surface structure beyond to the regular dressing sharpness and design characteristics (wheel porosity and hardness).

3. TEST METHODOLOGY

The same test methodology described in Oliveira *et al.*, 2010 was adopted to produce the textured parts by grinding. Texture type "pockets" and "cross linear" were selected to test the main process parameters. The first step is to select the proper texture characteristics for dressing based on the desired output. As mentioned, patterns can scaled up according to the selected speed ratio between wheel and workpiece during grinding. Figure 3 illustrates that initial consideration.

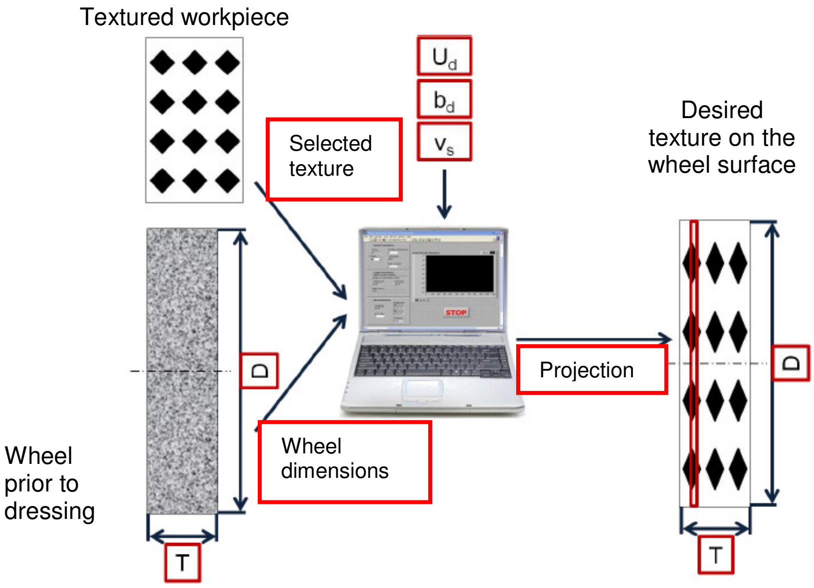


Figure 3 – Required steps to produce pattern workpieces (Bottene, 2012)

The next step is the pattern generation and mapping software adjustment to send the required control signal to the electro-mechanical actuator (shaker) to dynamically change the dressing depth according to the control parameters (wheel angular position and speed). The following dressing conditions were determined to produce the required pattern: cutting speed (v_s) = 30 m/s; single point dressing tool, dressing lead (S_d)=0.115 mm/rev; dressing overlap (U_d) =1; dressing depth (a_d)=0.2 mm, producing a pocket with three crests equally spaced on the wheel surface. Acoustic emission mapping was used to monitor the dressing operation. An aluminum oxide grinding wheel type (38A-80-KVHB) was used for the test experiments.

Once the wheel is dressed, the next step is to transfer the wheel pattern to the workpiece (Figure 4). Inconel cylindrical workpieces were used, with 25 mm diameter and grinding width = 50 mm. A proper speed ratio was selected. The following cutting conditions were used: v_s=30 m/s; grinding stock = 0.1 mm. Figure 5 illustrate the acoustic emission monitoring system used as quality control for the dressing operation.

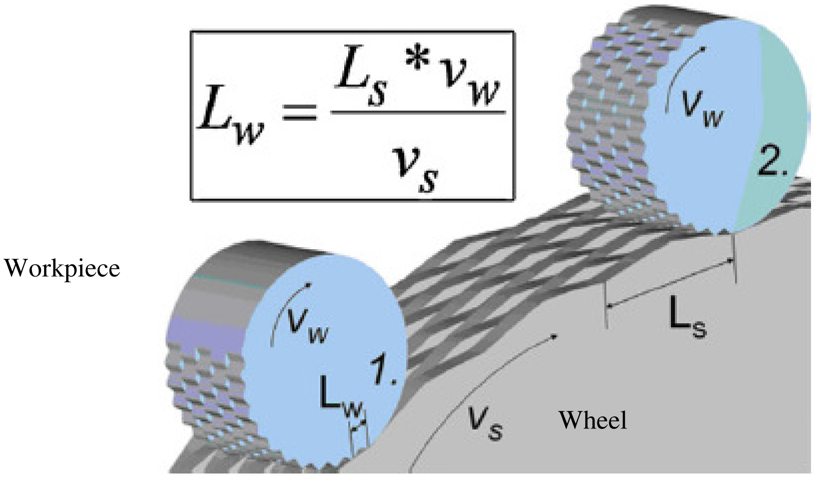


Figure 4 – Setup for transferring pattern from the wheel to the workpiece (Oliveira *et al.*, 2010)

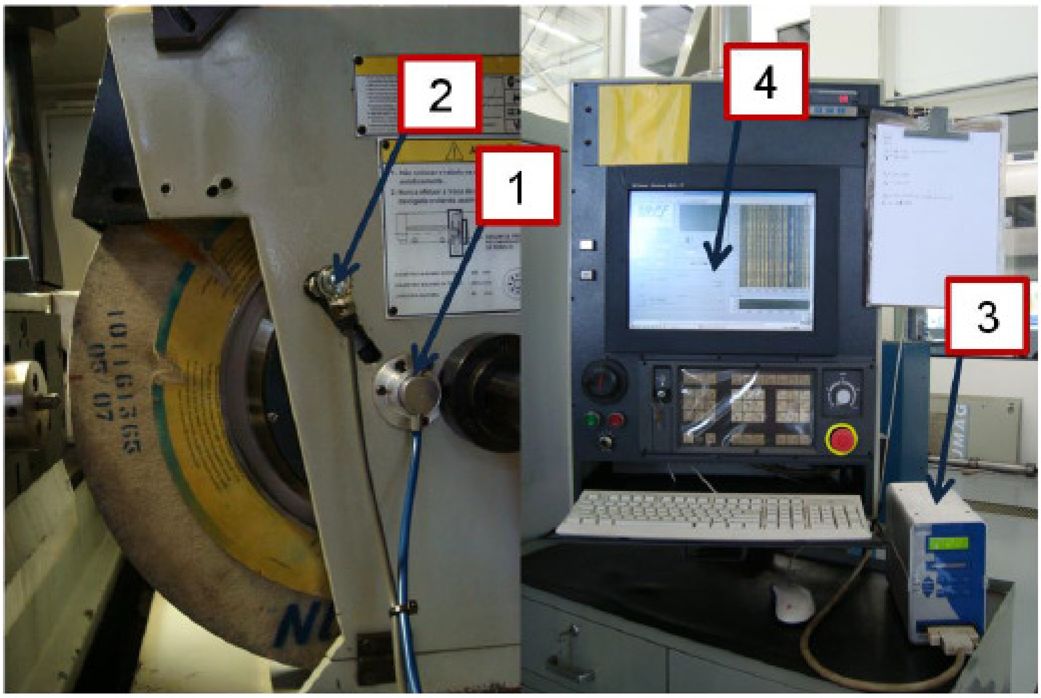


Figure 5 – Acoustic mapping system used as quality control for texturing during dressing (1-AE sensor, 2 – proximity sensor, 3 – AE signal conditioner, 4 – acoustic emission mapping software)

The first test parameter was the dressing overlap (U_d) influence in the quality of the obtained texture. Texture type pocket was selected as desired output. Three U_d conditions were chosen: U_d=1 rough grinding; U_d=3 semi-finishing and U_d=6 – finishing. The second set of tests was performed by evaluating the influence of the speed ratio (R) in the quality of the output pattern. Two R values were selected: R=5 and R=10, resulting in 15 and 30 features in the workpiece, respectively.

4. RESULTS AND DISCUSSION

4.1 Influence of the dressing overlap in the desired output texture

Figure 6 presents the results obtained during test 1 – influence of the dressing overlap in the quality of the textured parts. The acoustic emission map is presented on the left. Dark regions represent lack of contact between the dressing tool and the grinding wheel. Brighter areas indicate high acoustic emission intensity, resulted from tool-wheel interaction during dressing. Vertical dimension represents the wheel circumferential length and horizontal one the wheel width.

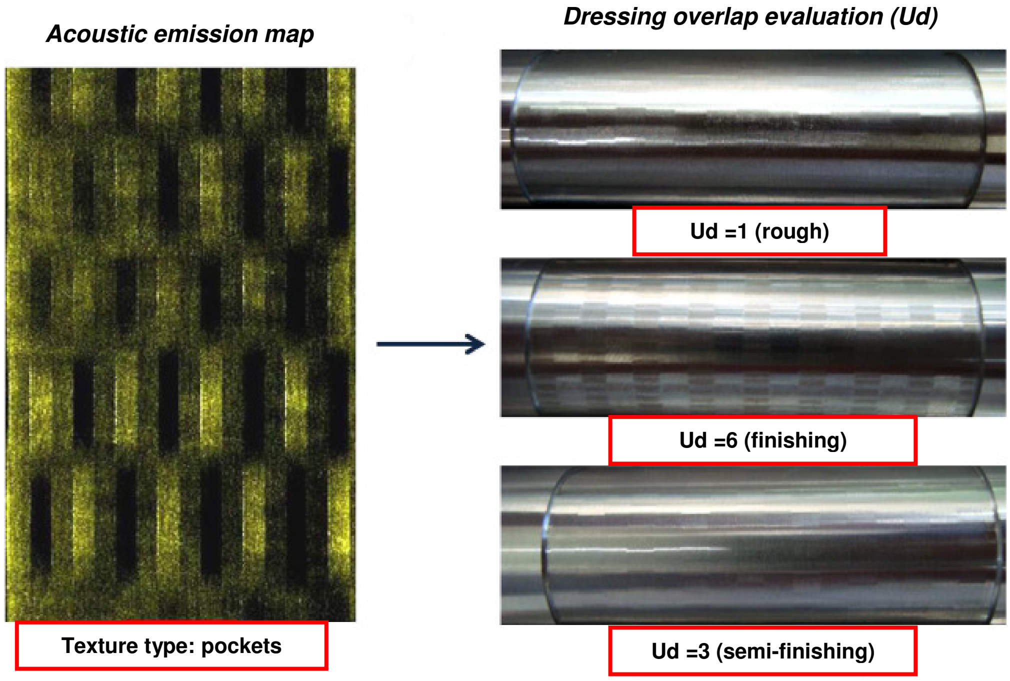


Figure 6 – Results of the dressing overlap influence in the obtained texture output (acoustic emission map – on the left; workpiece visual inspection – right side)

Regardless the selected dressing condition, in Figure 6, it was possible to verify that the pattern transfer occurred successfully, confirming the technique functionality. The ground surface quality was a combination of the wheel sharpness resulted from the selected dressing overlap. Increasing the dressing overlap (finer dressing condition) leads to a reduced sharpness of the wheel and material removal rate. Some regions of the workpiece presented superficial burn. For the rough dressing condition, no burn was detected, but the workpiece roughness increased. The semi-finished dressing condition was the one that presented the best compromise between workpiece quality and material removal rate, without workpiece burn. Additionally, workpiece roughness in the outermost portions of the parts in respect to the bottom of the pockets can be controlled by performing an additional dressing operation, right after the wheel texturing dressing procedure. That additional dressing is a regular (straight) dressing, with no dynamic change on the dressing depth. Figure 7 presents a resulting roughness profile of a textured workpiece, measured along its length. By using this combined strategy, the top roughness was reduced when compared to the bottom of the pockets.

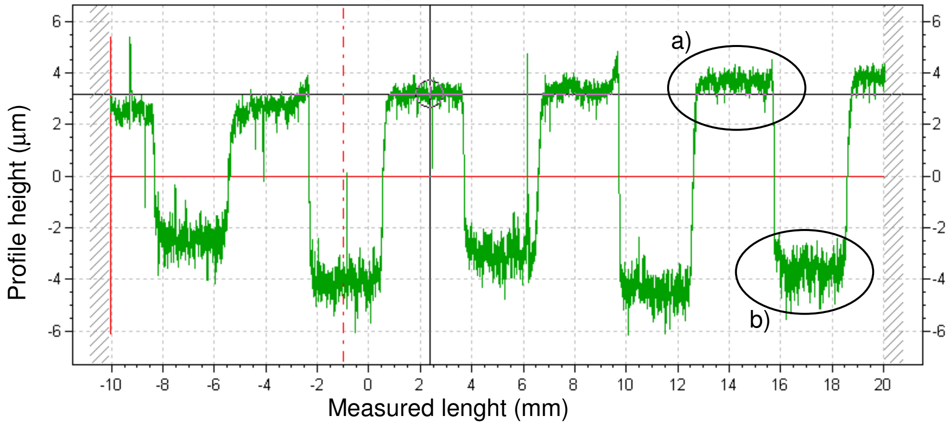
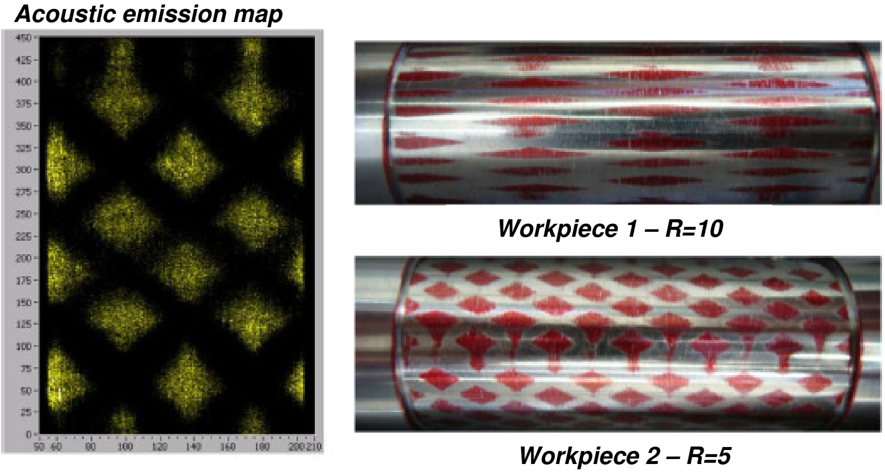


Figure 7 – Roughness profile of the textured workpiece at different regions of the pocket (a) -top and (b) - bottom

4.2 Influence of the speed ratio in the texture quality

Figure 8 presents the acoustic emission map during dressing and texture imprint (cross linear type) obtained at the workpiece surface when testing the influence of the speed ratio (R). The main objective was to evaluate the influence of the speed ratio in respect to the final dimensions of the workpiece. A commercial red marker was used to increase the texture contrast.



Workpiece 1 – R=10

Workpiece 2 – R=5

Figure 8 – Results of the speed ratio influence in the obtained texture output

The workpiece images in Figure 8 indicate that it is possible to scale-up and change patterns dimensions by selecting proper speed ratio. Axial dimension is fixed and related to the parameters set during the wheel texture imprint in dressing. Texture circumferential dimensions can be manipulated by adjusting the speed ratio (R) between wheel and workpiece, as demonstrated.

5. CONCLUSIONS

Based on the proposed technique and the test results, the authors conclude that:

- The proposed technique arises as viable alternative for parts texture, requiring minor modifications in the current dressing systems of commercial CNC grinder;
- The system was capable of transfer patterns from the wheel to the workpiece during regular grinding operation, without the need of additional machining processes;
- Besides the pattern selection, the quality of the ground surface (roughness, burnout) is still depended on the traditional dressing and grinding parameters, such as dressing overlap and grinding conditions;
- By selecting a proper speed ratio between wheel and workpiece it was possible to change pattern major radial dimensions, increasing the process flexibility.

6. ACKNOWLEDGMENTS

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