Optics & Laser Technology 80 (2016) 41–50

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Online, efficient and precision laser profiling of bronze-bonded diamond grinding wheels based on a single-layer deep-cutting intermittent feeding method

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ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form
8 October 2015
Accepted 29 December 2015
Available online 11 January 2016

Keywords:
Online laser profiling
Pulsed laser ablation
Diamond grinding wheel
Laser profiling efficiency
Surface contour precision

ABSTRACT

In this study, an online, efficient and precision laser profiling approach that is based on a single-layer deep-cutting intermittent feeding method is described. The effects of the laser cutting depth and the track-overlap ratio of the laser cutting on the efficiency, precision and quality of laser profiling were investigated. Experiments on the online profiling of bronze-bonded diamond grinding wheels were performed using a pulsed fiber laser. The results demonstrate that an increase in the laser cutting depth caused an increase in the material removal efficiency during the laser profiling process. However, the maximum laser profiling efficiency was only achieved when the laser cutting depth was equivalent to the initial surface contour error of the grinding wheel. In addition, the selection of relatively high track-overlap ratios of laser cutting for the profiling of grinding wheels was beneficial with respect to the increase in the precision of laser profiling, whereas the efficiency and quality of the laser profiling were not affected by the change in the track-overlap ratio. After optimized process parameters were employed for online laser profiling, the circular run-out error and the parallelism error of the grinding wheel surface decreased from 83.1 μm and 324.6 μm to 11.3 μm and 3.5 μm, respectively. The surface contour precision of the grinding wheel significantly improved. The highest surface contour precision for grinding wheels of the same type that can be theoretically achieved after laser profiling is completely dependent on the peak power density of the laser. The higher the laser peak power density is, the higher the surface contour precision of the grinding wheel after profiling.

1. Introduction

Bronze-bonded diamond grinding wheels are superhard material tools that are fabricated by sintering the world's hardest abrasive (diamond) and the bond with the highest holding strength (bronze). Strict requirements have been established regarding the dimension and the contour precision (i.e., several micrometers) of a profiled bronze-bonded diamond grinding wheel and the surface topography and landform (i.e., the protrusion height of a grain is approximately 1/3 the diameter of the grain) of a sharpened bronze-bonded diamond grinding wheel. Therefore, the precise dressing of a bronze-bonded diamond grinding wheel after the initial use or after it has become blunt is challenging. This challenge represents the primary problem that must be solved to realize the precision, high-speed and efficient grinding of a hard and brittle material. The laser dressing technique has exhibited substantial development potential in recent years due to its many advantages. For example, neither macroscopic force nor tool wear occurs during the dressing process, and the laser dressing technique can be used to dress an extensive range of grinding tools, such as parallel grinding wheels, formed molded grinding wheels, and ultra-thin cutting wheels. In addition, the laser dressing technique can be used to simultaneously and directly remove grains and bond. Thus, the laser dressing technique is expected to become an advanced, practical processing technique that can be employed to solve the problem of precision dressing of bronze-bonded diamond grinding wheels.

The laser dressing technique uses focused laser beams to cyclically scan the entire surface of a grinding wheel and selectively remove the material on the surface of the grinding wheel to enable the grinding wheel to achieve the required dimension and contour

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http://dx.doi.org/10.1016/j.optlastec.2015.12.021
0030-3992/

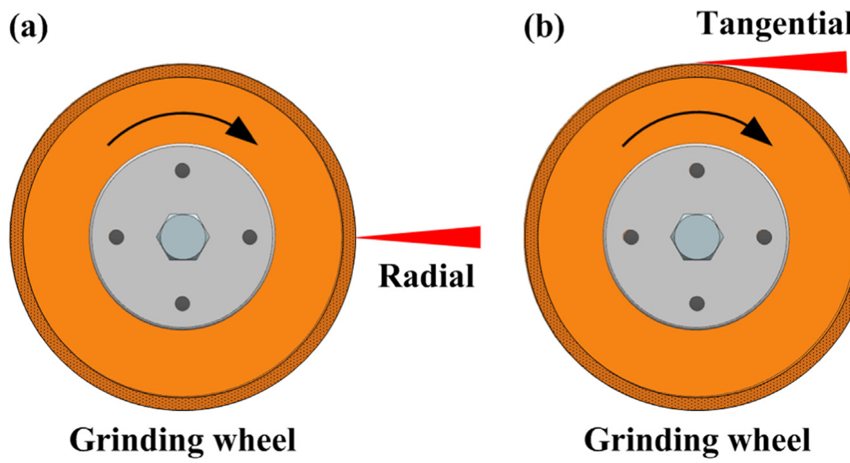

Fig. 1. Schematics of incidence of laser beams in the radial and tangential directions.

precision (i.e., profiling) and adequate surface topography and landform (i.e., sharpening). Two laser beam incidence modes exist: radial incidence (Fig. 1(a)) and tangential incidence (Fig. 1(b)). Previously, researchers from institutes such as the Institute of Laser Technology, Hunan University [1–3], the Institute of Machine Tools and Manufacturing, the Swiss Federal Institute of Technology (ETH) Zurich [4] and the Laser Zentrum Hannover e.V. [5,6] have primarily focused on the radial laser dressing technique. However, when laser beams are incident in the radial direction, they can only sharpen grinding wheels. They cannot precision profile grinding wheels for the following reasons: the beam cross-section of a laser beam gradually changes in the propagation direction (i.e., laser beams have focal depth characteristics); laser energy is not evenly distributed within a cross-section; and laser energy is approximately continuous in the propagation direction (i.e., lack of a distinct "knifepoint" position). Thus, when a laser beam cyclically scans the surface of the grinding wheel, the quantity of material removed at various locations on the grinding wheel's surface cannot be controlled. Therefore, the surface contour error of a grinding wheel cannot be pertinently and quickly corrected. In addition, satisfying the dimensional precision requirement of grinding wheels is challenging, that is, the goal of precision profiling cannot be achieved.

To solve this problem, Dold et al. [7] profiled an electroplated diamond grinding wheel by tangentially irradiating a pulsed laser beam (ytterbium:yttrium–aluminum-garnet (Yb:YAG)) onto the grinding wheel. The result indicated that high-quality and damage-free laser cutting of diamond grains was realized. Walter et al. [8] investigated the profiling of a hybrid bonded cubic boron nitride (CBN) grinding wheel using a tangential incident pulsed fiber laser beam. They successfully controlled the corner radii of the grooves on the grinding wheel's surface within 20 μm. Researchers were previously limited to preliminarily verifying the possibility of profiling superabrasive grinding wheels using tangential incident laser beams. However, they did not answer the following question: what level of surface contour precision could be achieved after a grinding wheel was profiled by a tangential incident laser beam? Thus, our research group proposed an online profiling approach that employs a tangential incident laser beam based on a multiple layering and layer-by-layer cutting method [9]. In this approach, a surface contour precision of approximately 20 μm for bronze-bonded diamond grinding wheels was attained after profiling, which solved the problem of the relatively low surface contour precision of grinding wheels after laser profiling. However, our proposed approach resulted in a new problem: low profiling efficiency. The causes of low profiling efficiency are as follows: when the multiple layering and layer-by-layer cutting method is used to tangentially profile a grinding wheel, with the continuous removal of the material on the grinding wheel's surface, an increasing amount of laser energy directly passes through the grinding wheel's surface, which results in a loss of energy. Due to the relatively shallow laser cutting depth (i.e., slightly less than the diameter of the laser beam), a large amount of the laser beam incident is reflected on the grinding wheel's surface. Compared with the laser focal area, the laser irradiation area is enlarged by tens or hundreds of times. These factors cause a sharp decrease in the effective power density during the laser profiling process. Therefore, profiling efficiency significantly decreases.

To address the difficulty of simultaneously considering efficiency and precision, this study proposes an online, efficient and precision laser profiling approach that is based on a single-layer deep-cutting intermittent feeding method. The basic principle and implementation steps of this approach are discussed. The effects of the laser cutting depth and the track-overlap ratio of laser cutting on the efficiency, precision and quality of laser profiling are investigated. Experiments on the online profiling of bronze-bonded diamond grinding wheels were performed using a pulsed fiber laser with optimized processing parameters.

2. Experiment

2.1. Experimental apparatus

Fig. 2 shows a schematic of the online laser profiling device. The average power (P_{avg}) of the selected pulsed fiber laser (model YLP-1/120/50/50-HC) for profiling is 50 W, the pulse repetition frequency (f) is 50 kHz, and the pulse width (τ) is 210 ns. The laser beam was transmitted via a single-mode fiber to the inside of the laser ablation head, which was fixed on a two-dimensional (X-axis: the radial direction of the grinding wheel; Y-axis: the axial direction of the grinding wheel) motorized displacement stage (model 7STA01A). Then, the laser beam was collimated and focused, after which it was incident on the surface of a grinding wheel (radius $R = 50$ mm; width $W = 10$ mm; grain size: 126 μm), which was installed on a precision surface grinder (model MGS-250AH). The focal spot diameter ($d = 2r$) of the laser beam was 35 μm. A charge-coupled device (CCD) laser displacement sensor (model LK-G80) for measuring the surface contour precision of the grinding wheel was fixed on the motorized displacement stage and moved with the ablation head in synchronization. The sampling frequency of the laser displacement sensor was set at 20 kHz.