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A Review of the Superfinishing Method: Application to Precise Crankshaft Machining

Nguyen Thi Linh[1], Quach Vu Hieu[2, *]
[1]The central college of transport 1, Thuy An, Ba Vi, Hanoi, Vietnam
[2]School of Mechanical and Automotive Engineering, Hanoi University of Industry, 298 Cau Dien, Bac Tu Liem, Hanoi, Vietnam
***** Corresponding author: vuhieuquach@gmail.com

Abstract—*The process of crankshaft finishing has witnessed significant advancements in recent years, fueled by remarkable progress in science and technology. Modern single multi-spindle rotary grinders have revolutionized the field, enabling high-precision machining of crankshafts. This innovative setup facilitates the determination of optimal finishing levels based on temperature prediction, leading to reduced machining time, minimized thermal damage, and diminished wheel wear. This comprehensive paper delves into the latest advancements in crankshaft polishing, meticulously evaluating the contributions of production process optimization and boron nitride (CBN) grinding wheel modification. By thoroughly analyzing established grinding methods, the paper sheds light on the most effective approaches for achieving superior crankshaft finishing outcomes.*

Keywords*— Automotive, CBN, crankshaft, grinding, crankpin.*

I. INTRODUCTION

Currently, the crankshaft remains the most widely used automotive drivetrain system globally. Therefore, there is a significant demand for advancements in crankshaft production, both in process and technology [1-5]. The main challenges hindering development are the high costs of components and the performance and quality not meeting expectations. Original Equipment Manufacturers (OEMs) are aiming to reduce grinding cycle times, proposing the use of high-performance superabrasive methods that exhibit minimal wear. Additionally, to enhance performance and precision, special requirements such as crankshaft roundness accuracy need to be considered. Future advancements in crankshaft grinding will include the application of advanced grinding methods, optimization of specific grinding processes, adjustment of superabrasive grains, and the development of new wheels tailored to specific specifications. The following sections will discuss process improvements and then propose new designs for grinding wheels within this context.

II. MACHINE MANUFACTURERS PROPOSE NEW METHODS

Many innovative methods have been proposed by recognized machine tool manufacturers and have been patented. Some notable companies with their own grinding design processes include Erwin Junker Maschinenfabrik, Cinetic Landis Grinding Limited, and Jtek Corporation.

In 1986, Toyoda Koki Kabushiki Kaisha (now Jtek Corporation) announced a patented improvement in the plunge grinding process [1] for crankshaft grinding. Jtek Corporation proposed using a thinner grinding wheel to enable angle plunge grinding of the shoulder with adjacent cylindrical parts of the crankshaft. A crankpin grinding process using this improved plunge method is performed from A to J as shown in Figure 1 below.

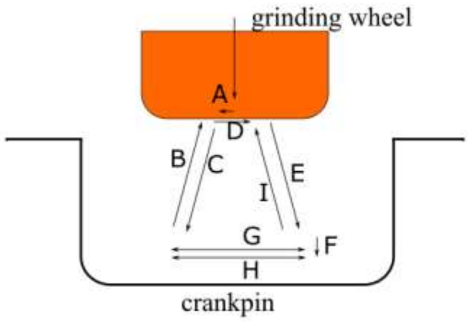

Figure 1: Plunge angle grinding method illustrated [1].

Based on the angle plunge grinding method [1], in 2005, Cinetic Landis Grinding Limited announced a patent describing an improved method for grinding the side face and the adjacent cylindrical part [2]. Figure 2 illustrates the improvement of this method as it completes the cylindrical surface after the grinding wheel processes the side face and moves out. This new technology allows for better control of speed, dwell time, and coolant flow pressure in each cycle, thereby reducing thermal damage to the workpiece.

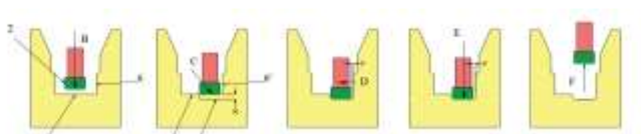

Figure 2: Steps B to F outline the grinding process in Landis' patent [2].

Continuing with Jtek Corporation, in 2006, they identified and improved upon their 1986 angle plunge grinding method [3]. Simultaneous grinding of side faces, diameters, and radii presented several limitations in material removal. Additionally, the old method did not provide sufficient coolant flow, leading to increased temperatures due to clogged grinding wheels, resulting in more friction and potential damage to the components from heat. This improved angle

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plunge method is illustrated in Figure 2. They proposed using a smaller angle when plunging into the side face of the crankshaft to reduce the contact area between the grinding wheel and the workpiece.

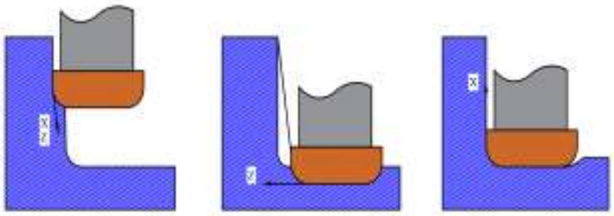

Figure 3: Grinding process steps according to US Patent 7,118,453 [3].

In 2008, Jtek Corporation once again announced a new patent [4], which improved upon previous methods. During machining, the grinding wheel wears out quickly as the radius is also involved in the material removal process, leading to increased time for regrinding the wheel and potential impacts on the geometric surface of the grind. The proposed solution was to use the tip and side of the grinding wheel instead of the radius. Figure 3 presents the two technological options [3] and [4] to help identify the differences. The material removed by the grinding wheel's radius is marked by shaded areas. The grinding steps are shown sequentially from 1-6 and from A1-A6. The lifespan of the grinding wheel is extended with this new method.

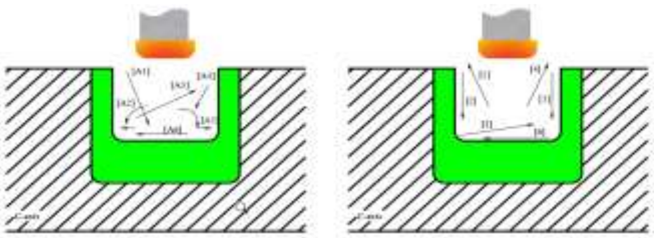

Figure 4: Prior technology [3] on the left and an enhanced method for grinding crankshafts on the right [4].

In 2009, Jtek Corporation announced another method for crankshaft grinding [5]. This method, illustrated in Figure 4, allows the grinding wheel to move between the side faces while providing better cooling and reducing the risk of grinding burn. Additionally, the load of the grinding wheel assembly on the workpiece is more evenly distributed, which helps to minimize grinding wheel wear.

Figure 5: Wheel displacement between two sides [5].

III. KEY OBJECTIVES IN CRANKSHAFT GRINDING RESEARCH

An optimized grinding process for the crankshaft plunge grinding method was applied in 2003 [6] on a Landis grinding machine. This model measured grinding forces using sensors at critical points such as the headstock, tailstock, and steadies. In 2005, Oliveira's team [7] conducted experimental comparisons of three different grinding strategies: (1) multi-face grinding, (2) multi-axis grinding, and (3) plunge grinding. These experiments aimed to determine the most suitable method for minimizing grinding wheel wear. Among these, the multi-face grinding method, with its adjustable material removal rate and controlled process, was found to be the most effective option for optimization.

Krajnik et al. [8] published a review on modeling the fundamental grinding parameters for different grinding wheel profiles in the most commonly used methods for industrial crankpin grinding in the automotive industry. Scania CV AB [9] also utilized a temperature-based method to determine the material removal rate. These new methods calculate the maximum surface temperature of the workpiece to ensure it remains within the safe thermal endurance zone using the following formula:

$$\Theta_m = \frac{1.064}{\left(k.\rho.c_\rho\right)^{\frac{1}{2}}} . \frac{e_w.ag(s).Q_w{}'(s)}{l_c(s).v_w} \qquad (1)$$

In which Θ_m is the surface temperature, material constants such as k, ρ, and c_p; v_w is the workpiece speed, $Q_w'(s)$ is the material removal rate, l_c is the geometrical contact length between the grinding wheel and workpiece, and ew is the specific grinding energy measured on the workpiece. The aggressiveness (ag(s)) is a dimensionless parameter proportional to the square of the maximum chip thickness [10] and is calculated for each part of the grinding wheel profile.

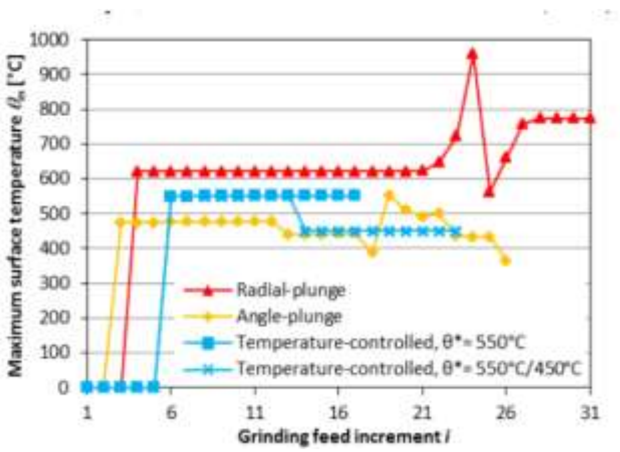

Figure 6: Comparison between the standard grinding process and the temperature-controlled process [8].

Model performance based on temperature [9] is compared with the radial plunge and angle plunge grinding processes commonly used in automotive OEMs [8]. The maximum surface temperatures of all three methods are predicted in Figure 6. Temperature control experiments at 550°C show productivity reaching limits, or at 450°C, surface integrity can be improved in the final six steps of the grinding cycle. In addition, some preset manufacturers did not yet achieve an optimal level.

IV. GRINDING WHEELS FOR CRANKSHAFT GRINDING

The technological process and effectiveness of the grinding method significantly influence project success. Additionally, tool costs and the current state of grinding wheels, which experience uneven loading leading to varying wear at different positions and potential wheel steps, cannot be overlooked. These factors provide a basis for researchers to develop and improve methods aimed at reducing incurred costs. Considering specific details of the crankshaft grinding process, there are two types of wear mechanisms: attritious (or abrasion wear) and fracture wear [11]. Attritious wear uniformly increases the grinding wheel surface and typically occurs during flat grinding, while fracture wear is often caused by a combination of mechanical and thermal stresses within the grinding grits. These two wear mechanisms depend on the type of abrasive grit, processing conditions, application specifics, and the type of workpiece material.

Radhakrishnan's group [12] conducted research on the wear of grinding wheel radii. They concluded that this wear can be monitored by setting force thresholds to help track and determine the timing for tool repair or replacement. Subsequently, in a publication [13], they introduced grooves on the upper surface of the grinding wheel to minimize wear on the wheel radius. This experimental method aimed to reduce grinding forces and decrease wear by enhancing cooling and cleaning capabilities, thereby mitigating grinding wheel wear. Additionally, Jackson studied materials used in grinding wheel manufacturing [11, 14]. He concluded that each component of the grinding wheel could be a variable affecting the complex characteristics of friction and wear.

In the field of grinding, CBN (Cubic Boron Nitride) abrasives possess superior characteristics compared to conventional abrasive types. Figure 7 illustrates that CBN offers high hardness, along with chemical inertness and high thermal conductivity. The investment trend in CBN abrasives has been increasingly hot in recent years, facilitating its ongoing development. In the realm of crankshaft grinding, there exists a specific standard for using CBN grinding wheels [1, 3, 5, 9], which enhances performance (Figure 8). A study combining crankshaft grinding with electroplating by Comley et al. [15] yielded impressive results with material removal rates up to 2000 mm3/mm without being affected by temperature, thereby preventing damage.

Recently, there have been many advancements aimed at making grinding wheels more specialized. For instance, Jtekt Corporation [16] has patented research on a grinding wheel designed with various abrasive grain sizes and different bonding methods (Figure 9) to address tooling issues when grinding crankshaft angles.

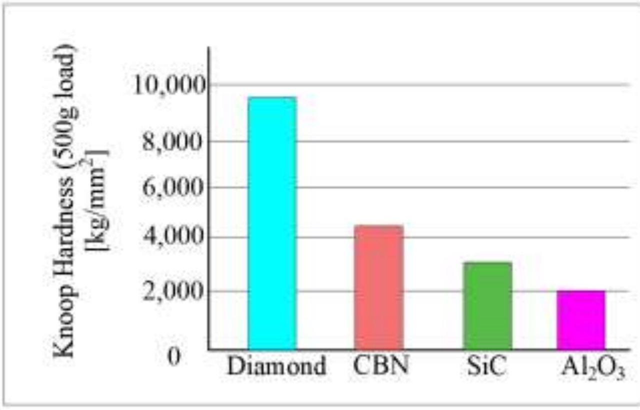

Figure 7: Hardness of superabrasives and conventional abrasives.

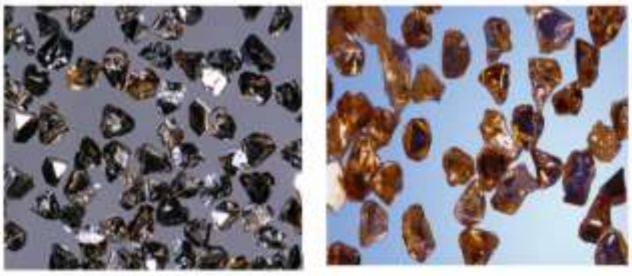

Figure 8: Two types of CBN grains from Element Six with distinct characteristics: ABN200 on the left, known for being more brittle and having lower thermal stability, and ABN800 on the right, which is more durable and has higher thermal stability.

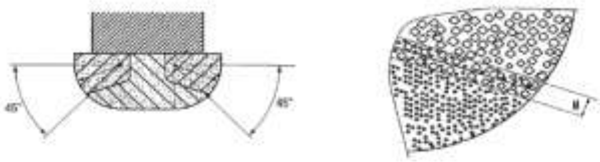

Figure 9: Cross-sectional view of the abrasive layer structure featuring three distinctive sections (left); variations in abrasive grain size between the two outer layers and the middle mixed layer (right) [16].

The patent proposes a grinding wheel design to address two specific issues during usage - grinding wheel wear near the side surface and surface quality on the crankpin surface. This design uses a two-stage rotating wheel with different abrasive grit sizes and bond patterns. In the first section, at the crankpin surface and extending into the radius, smaller abrasive grains are used with a softer bond to achieve a smoother surface finish. In the second section, at the side surface and extending into the radius, larger abrasive grains are utilized with a harder bond to minimize grinding wheel wear.

V. REPAIRING GRINDING CAKE IS USED IN CRANKSHAFT GRINDING APPLICATION

Repair of grinding wheels used in crankshaft grinding applications is crucial due to the wear that alters the wheel profile, increases grinding forces, and reduces surface quality. This necessitates periodic truing to avoid thermal damage and geometric inaccuracies. Grinding performance depends on the grinding tool, grinding system configuration, and grinding parameters. Among these parameters, the grinding parameters are the sole factor that can be easily adjusted to meet the

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surface requirements of the workpiece.

Depth of cut, cross-feed ratio, and feed rate ratio are adjusted to achieve the desired surface finish. According to Malkin and Murray [17], when the grinding parameters produce a smooth wheel, the abrasive grains tend to flatten; conversely, they fracture when producing a rough wheel. This is particularly true for conventional grinding wheels. The article also discusses the intersecting angle, which affects the severity of truing and energy consumption.

Brinksmeier and Cinar [18] pointed out that the profile of CBN grinding wheels "loads" after grinding, causing the protruding parts of the abrasive grains to become smaller. They explained the severity of wheel dressing by measuring the collision frequency between CBN and diamond abrasive grains on the grinding wheel.

The grinding setup depends on the grinding requirements and the application of the wheel. If only surface grinding of the workpiece is needed, the methods usually involve grinding across the width of the wheel. However, crankshaft grinding requires grinding around the circumference, radius, and side faces, demanding a more complex strategy. One approach is cylindrical grinding, allowing grinding over 180° (Fig.10). [19]. This arrangement is commonly used in crankshaft grinding machines to achieve a uniform grinding shape around different parts of the wheel due to its single grinding roll shape.

Figure 10: cross-axis dressing [19]

VI. SUMMARY

This article explores various aspects of crankshaft grinding technology: from methods developed by machine manufacturers and recent process advancements in the automotive industry, to grinding solutions and wheel improvements. Several processes have been identified, primarily based on plunge angle grinding. The latest proprietary unit [9] in this field has analyzed the fundamental principles of the grinding process and designed a method to control surface temperature around the workpiece cutting edge. This method allows the process to be performed near the crush-burn threshold, resulting in higher productivity. The driving force behind this development lies in the localized wear of grinding wheels and thermal damage to the workpiece when using current grinding technologies on the market, such as plunge grinding.

The research field on the application of grinding wheels in crankshaft grinding is still relatively new. Current evaluations indicate that Cubic Boron Nitride (CBN) grinding wheels have met industrial standards, leading to a reduction in the use of conventional grinding wheels. A patent granted in 2017 describes the use of grinding wheels with adjusted compositions for different parts of the crankshaft [16]. This demonstrates manufacturers' increasing awareness of the complexity of the process and grinding behavior at various positions on the wheel in this specific application. Research on grinding materials to find optimal solutions is also gaining momentum. Despite many opportunities for improvement, understanding the fundamental principles of this application is crucial. For instance, crankshaft sections need to withstand high localized impact loads while minimizing wear.

The grinding wheel wear plays a crucial role in influencing the performance of crankshaft machining. However, current standard wear parameters may not suffice to optimize the process for various grinding machine systems developed by manufacturers. Several models have been proposed to integrate grinding parameters and describe the severity and strength of the grinding wear process. However, compared to grinding tools, research on grinding wheel wear in crankshaft machining applications is still limited. Due to the specific design requirements of crankshafts, which demand different quality standards and technical specifications for each part of the workpiece, various points on the grinding wheel periphery must endure different grinding conditions and loads. This necessitates the use of diverse types of grinding wheels. This can be done by adjusting and optimizing the grinding wheel and grinding process. Therefore, it is crucial to understand the different grinding configurations on various machines and to optimize the grinding process for different parts of the grinding wheel.

Despite advancements in grinding methods and process innovations in crankshaft machining, this assessment indicates a need for more focus on developing customized grinding wheels and optimizing the grinding process. Considering the specific geometry and dynamics of grinding systems on different machines will also yield significant benefits.

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