Development of High-Quality Grinding Technology Using a CBN Wheel

H. MORITA

CBN grinding is characterized by both high productivity and stable grinding accuracy. We have strived and succeeded to add a new technology to CBN grinding which results in a high-quality surface finish by reducing both chatter and waviness, making it possible to use a CBN wheel to maintain a smooth surface from 1 μm to less than 0.5 μm. We have presented a new option of a CBN wheel for high-quality grinding primarily based on the conventional wheel.

Key Words*: cylindrical grinding, CBN wheel, high-quality surface finish, visualization, quantification*

1. Introduction

In recent years, the issues faced by manufacturers of high-quality products are the decrease in experienced workers who possess high-quality machining skills and a shortage of production shop floor personnel due to a delay in developing next generation workers. In response to this situation, there is a need to promote machining technology and equipment offering high-quality machining and high added value which is not reliant on experienced workers.

As the final finishing process, for the grinding process in particular, it is necessary to always secure the advantage due to the competitiveness of product cost and quality, and there is a strong demand to achieve both high productivity and more stable high-quality machining.

In order to meet customer needs, JTEKT is working to improve surface texture through using a CBN (cubic boron nitride) wheel characterized by high productivity and stable grinding accuracy. This paper will introduce the new option JTEKT can now offer our customers of using a CBN wheel for high-quality grinding that primarily used with conventional grinding wheels.

2. Current Status and Issues of High-quality Grinding

In regards to high-quality machining, this time, we targeted cylindrical workpieces with a finishing grinding surface roughness between 0.08 to 0.3 μmRa (shafts, spindles, tool holders, etc.).

Presently, in the case of workpieces for which high-quality grinding is required, high-mix small-volume production is the mainstream approach, and conventional wheels are most commonly used on general-purpose cylindrical grinders. In such a case, the production line is small-scale and comprises a small number of general-purpose machines, however each time the workpiece width and shape changes, there is a need to perform set-up changeover, such as wheel change, tooling change, dressing and grinding accuracy adjustment. As a result, the percentage of operating time occupied by actual grinding is low, meaning it is difficult to make productivity improvements.

Next, we compared the conventional and CBN wheels from the perspective of productivity and wheel life (**Fig. 1**). The conventional wheel has low grinding ability Z' (grinding stock cross-section area per unit of time) therefore is inferior in terms of productivity. The general grinding ability Z' of a conventional wheel is 1 - 3 $mm^3/(mm\cdot s)$. The hardness of the abrasive grains used in a conventional wheel is between 2 100 and 2 500 knoop hardness when made from either aluminum oxide or silicon carbide. Moreover, the bonding agent holding the abrasive grains together is low strength, meaning that the abrasive grains break and fall off due to grinding force and self-sharpening is carried out frequently. This means that the state of the wheel surface changes as machining progresses, and the assumption is short wheel life and frequent dressing.

Meanwhile, in the case of CBN wheels, grinding ability Z' is between 1 and 15 $mm^3/(mm\cdot s)$ and high-ability grinding with 5 times greater productivity than the conventional wheel is possible.

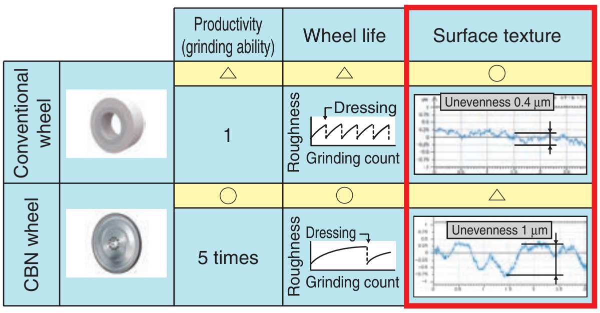

Fig. 1 Comparison of conventional wheel and CBN wheel

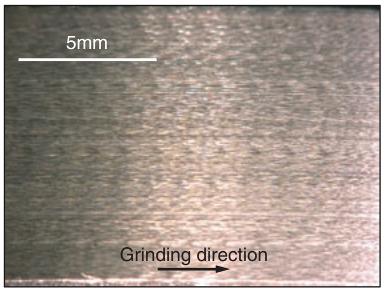

Fig. 2 Scaly pattern (grinding surface magnified picture)

The hardness of the CBN abrasive grains is 4 700 knoop hardness, which is second hardest after diamond (7 000). Moreover, by holding the CBN abrasive grains with high-strength bonding agent (vitrified bond), there are few incidences of abrasive grains breaking or falling off, therefore changes in the state of the wheel surface as machining progresses are minimal, and grinding accuracy can be maintained for a long period of time. In light of this fact, there is a proactive shift away from the conventional wheel to the CBN wheel for grinding processes in the mass production of automotive parts, etc. which require a surface roughness of 0.3 to 0.5 µmRa. Moreover, CBN wheels have a long interval between truing (wheel correction), therefore have a long life around 30 to 50 times longer than the conventional wheel, meaning increased net rate of actual machining, thus improved productivity.

Next, we will make a comparison of the "grinding surface texture", which is a key point of high-quality grinding. In grinding where high surface quality is required, emphasis is placed not only on surface roughness, straightness, roundness and other grinding accuracies, but also on the "aesthetic quality" when light is reflected off the grinding surface. In the case of a CBN wheel, even if the surface roughness is the same level as that when a conventional wheel is used, it is more likely for "chatter" to occur in the vertical direction of the grinding streaks and an even "scaly pattern" to occur in the direction of grinding (**Fig. 2**).

Chatter and scaly pattern are expressions of CBN abrasive grains making solid contact with a workpiece due to insufficient self-sharpening. Moreover, in regards to the grinding surface cross-section shape in the grinding direction, if the conventional wheel is used, there is unevenness in the grinding surface, however the profile blurred. In contrast, when a CBN wheel is used, the unevenness has a tendency to be notable. As such, in CBN wheel grinding, which is characterized by high productivity and stable grinding accuracy, there is a need to improve the surface texture to achieve high-quality grinding.

3. Steps to Achieving High-quality Grinding Using a CBN Wheel

Grinding surfaces are strongly influenced by many factors, including equipment, tools, material, grinding conditions, grinding fluid, machining environment, etc. and if any of these factors is lacking, a high-quality grinding surface is unachievable. Particularly in the final grinding process of finishing, the dimensions are in units of mere microns and the unit for surface quality even takes into account any minute unevenness in the realm of sub-microns. In order to achieve high-quality grinding using a CBN wheel, JTEKT took the below steps.

①Establishment of measurement technology/analysis method for visualization of surface texture
②Analysis of factors causing poor surface texture
③Verification of countermeasures/benefits

4. Establishment of Measurement Technology/Analysis Method for Visualization of Surface Texture

To date, surface texture was measured using a stylus-based profilometer or roundness meter to evaluate the depth, pitch, frequency analysis, etc. of the grinding surface unevenness in a workpiece cross-section. Using this method, only the one cross-section that the stylus passes across is evaluated. In regards to the scaly pattern notable with CBN grinding, the status of the grinding face unevenness depends on the position of the wheel in the width-wise direction, therefore absolute values such as the depth of the unevenness, etc. differ depending on the measured position, and measurement on one cross-section alone has analysis limitations.

Taking an uncompromising stance on the "aesthetic quality" of the finish grinding surface, JTEKT added multiple analysis methods to measurement data using an optical interference non-contact 3D profiler and, consequently, became able to faithfully reproduce, measure and analyze the "scaly pattern" which conventionally could only be observed visually on a surface with information on 3D height (**Fig. 3**). As a result, it is now possible to quantitatively correlate actual changes in the grinding surface with factors causing poor surface texture and effectively implement countermeasures for improving surface texture based on the contribution rate of the problematic factor.

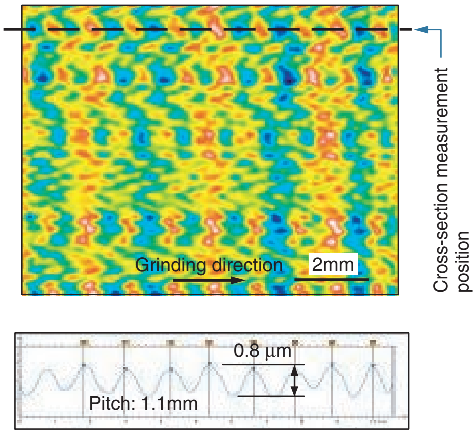

Fig. 3 Surface texture 3D measurement example

5. Analysis of Factors Causing Poor Surface Texture

We measured multiple cross-sections of the face ground by a CBN wheel and performed frequency analysis of the surface unevenness based on equipment specifications, grinding conditions, etc.

As a result, we observed that the main components for chatter and scaly pattern were equivalent to the wheel rotation frequency. We then decided to focus on the vibration of the wheel spindle rotation system, wheel correction, grinding conditions and grinding force as factors causing poor surface texture.

In general shaft-like cylindrical grinding cycles, after the wheel approaches the workpiece at rapid feed, it performs rough grinding, precision grinding, fine grinding, spark-out, traverse feed, then, ultimately creates a finished surface. When establishing a countermeasure, JTEKT paid particular attention to the fact that the minute infeed processes of fine grinding, spark-out and traverse feed are what determine surface quality, and, due to the CBN abrasive grains being high-strength, minute breakage is unlikely to occur, hence, abrasive grains do not become wedged in the workpiece during minute infeed processes, and top slip is likely to occur.

6. Development of Element Technology for CBN Wheel High-Quality Grinding

JTEKT developed element technology to achieve high-quality grinding using a CBN wheel in response to requests for improved productivity from customers who had used the conventional wheel to perform high-quality grinding. High-quality grinding using a CBN wheel has the following four features (**Fig. 4**).

①Thorough vibration countermeasure

In order to reduce the vibration caused by equipment-related factors during the minute infeed processes which determine high-quality grinding, JTEKT measured the respective amplitudes of vibration for the wheel spindle, motor and pulley; all of which are rotating body systems causing vibration, assembled the unit after correcting dynamic balance and, ultimately, established a thorough

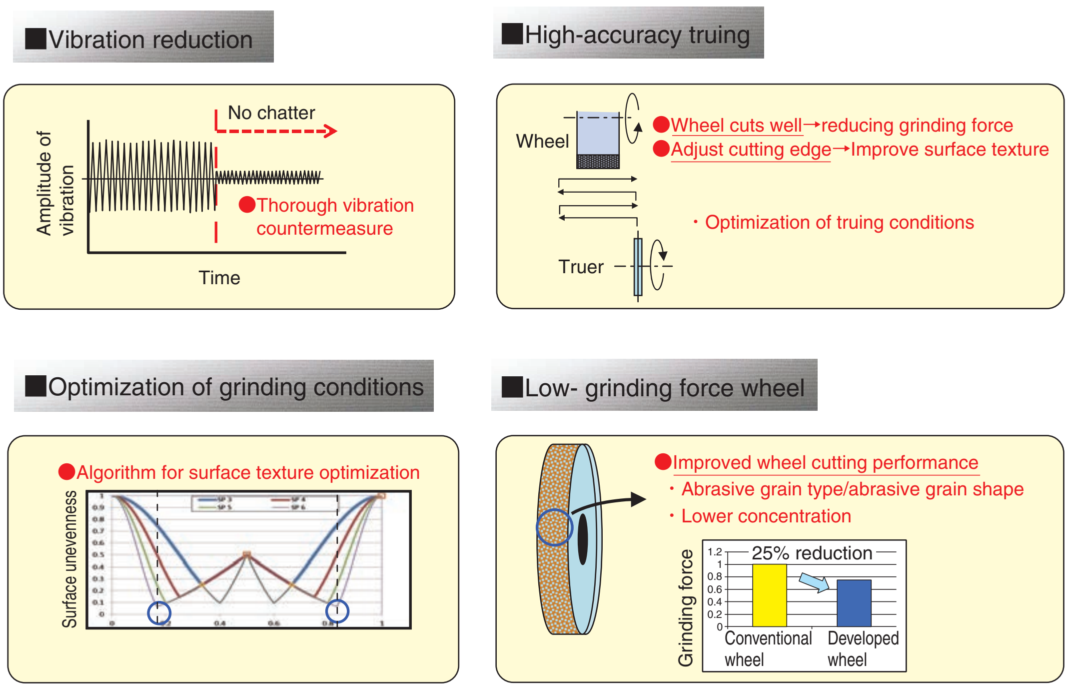

Fig. 4 Features of high-quality grinding with a CBN wheel

vibration countermeasure to control vibration in front of the wheel head, which is close to the grinding point, at a set level.

②High-accuracy truing technology

In the truing process that forms the cutting edge of the CBN wheel, we used a rotary diamond truer to form a sharp cutting edge and optimized truing conditions by adjusting the cutting edge tips to be uniform.

③Algorithm for Optimization of Surface Texture

When grinding rotating workpieces, there is a need to minimize the relative vibration of the wheel and workpiece, however it is impossible to eliminate this entirely. In relation to the forced vibration caused by disturbance and the self-excited vibration caused by changes in wheel cutting performance, we reduced grinding surface unevenness with an algorithm to find the grinding conditions which minimize uncut portions and also considered the geometric interference of the wheel and workpiece.

④Development of a low-grinding resistance wheel

In order to even out the final grinding surface in minute infeed processes during high-quality grinding, we developed a CBN wheel with reduced grinding force. To secure wheel cutting performance, we focused on abrasive grain type, abrasive grain shape, lower concentration and improved bonding agent to ultimately reduce grinding resistance by 25% compared to a conventional wheel.

7. Examples of High-Quality Grinding

We have used cylindrical plunge grinding and cylindrical traverse grinding as examples of high-quality grinding with a CBN wheel (**Fig. 5-1**, **Fig. 5-2**).

This has improved the scaly pattern that previously appeared on the grinding surface when a CBN wheel was used, and reduced surface unevenness to 0.5 μm or less. This technology can be applied to cylindrical grinders such as e300G, e500G, GE4i and GL32Mi (**Fig. 6**).

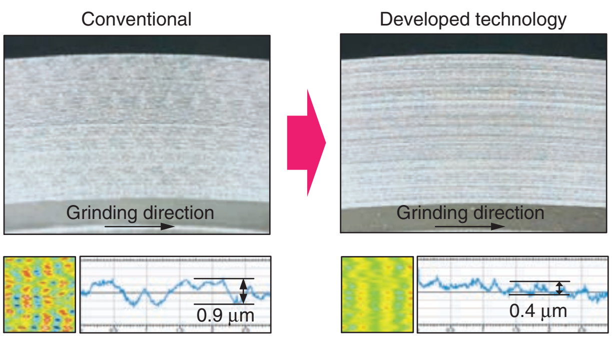

Fig. 5-1 Grinding example (Cylindrical plunge grinding)

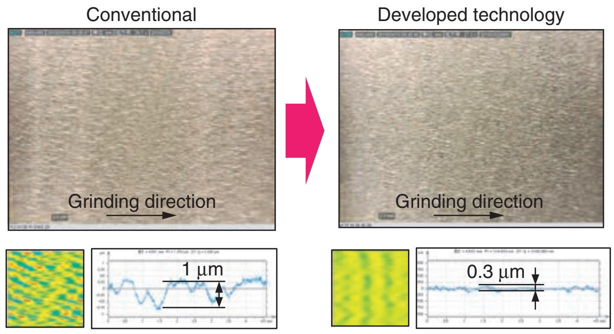

Fig. 5-2 Grinding example (Cylindrical traverse grinding)


Fig.6 High-quality surface cylindrical grinder with CBN wheel

8. Conclusion

JTEKT has newly developed element technology for high-quality grinding using a CBN wheel, which is capable of realizing high productivity and stable grinding accuracy.

We have always strived to establish innovative technology with high added value such as high productivity, high accuracy, high reliability and high functionality. As one of Japan's leading manufacturers of grinders, JTEKT wishes to continue supporting the world's monozukuri through machine tools by proactively developing and proposing machine tools and machining technology that anticipate our customers' needs.

H. MORITA*

* *Machine Tools & Mechatronics Engineering Dept., Machine Tools & Mechatronics Operations Headquarters*