

Development of Minimized Coolant Supply Technology in Grinding (ECOLOG Grinding TYPE II)

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In grinding, a large amount of grinding fluid (coolant) is supplied in order to break the air flow circulating with the rotating grinding wheel and reach the grinding point. In this study, technology to reduce the required amount of coolant supply has been developed whereby air supplied above the grinding point from the side of the wheel effectively intercepts the air flow around the wheel. Evaluation testing has confirmed that in high-efficiency grinding, grinding performance equivalent to that of the conventional method can be achieved with half the coolant supply. In addition, wheel spindle power loss due to coolant has been reduced by around 50%. In the case of grinding where the grinding point moves up and down over a wide area, it has been confirmed that coolant reaches to the lower part of the wheel, unlike conventional methods.

Key Words: environment, coolant supply system, air flow, high-speed grinding

1. Introduction

Due to the increasing environmental awareness in recent years, environmental conservation and energy-saving initiatives have been increasingly and actively promoted in production sites. One well-known effort is to reduce the amount of machining fluid used (hereinafter called coolant). In cutting, such methods as dry machining and MQL (Minimum Quantity Lubrication) machining are starting to be utilized in actual production sites¹⁾.

On the other hand, as the grinding wheel is an aggregate of cutting edges with negative rake angles, grinding generates more heat than cutting and requires a large amount of coolant to meet high accuracy and high quality requirements. This is why there have been very few grinding cases reported where the amount of coolant used is reduced in production sites.

In an effort to reduce the amount of coolant in grinding, the author's team has already developed a semi-dry grinding system (ECOLOG grinding TYPE I) which supplies minimal lubricant mist and minimal coolant. We have reported that this system enabled the cylindrical grinding of transmission shaft components with a coolant supply approx. 1/100 of the conventional grinding²⁾. However, depending on the material and shape of the workpieces as well as the required accuracy levels, there have been limitations in application. In addition, there is the issue of grinding burn, which is more likely to occur as the grinding stock removal rate increases.

Therefore this time, so as to widen the application, we have developed a new coolant supplying system,

"ECOLOG grinding TYPE II," aiming at the reduction of coolant supply in the high-efficiency grinding area, which has significantly reduced the amount of coolant supply by effectively blocking the air flow circulating with the rotating grinding wheel.

This report presents the outlines and application examples of this new technology.

2. Conventional Coolant Supply Technology and Issues

Figure 1 shows an example of the relationship between the target workpiece and the coolant supply amount for external grinding. Generally, the higher the grinding stock removal rate, the more heat generated on the grinding point, and hence more coolant tends to be supplied. Also, in the case of components such as crankshafts and camshafts where high productivity is required, the wheel peripheral speed tends to be increased, and air flow circulating with the rotating grinding wheel prevents the coolant from reaching the grinding point. Thus, even more coolant needs to be supplied so that the air flow can be penetrated.

As such, in order to ascertain the air flow generated in the grinding wheel periphery, the air flow velocity was determined experimentally by measuring air pressure with a pitot tube placed in the vicinity of the wheel outer periphery.

From a comparison between the wheel peripheral speed and air flow velocity at the same distance from the wheel surface, as shown in Fig. 2, it was found that

the higher the wheel peripheral speed, the higher the air flow velocity became. It was also found that the air flow velocity was greater in the area closer to the wheel periphery.

One typical method to block this air flow is to install an air-blocking plate, called a baffle plate near the wheel surface³⁾. This method, however, involves such issues as difficulties in adjusting the clearance with the wheel and adjusting as to the wheel diameter change. This is why high speed grinding machines often use either high volume or high pressure coolant to break the air flow. Because high pressure pumps are associated with issues like high equipment cost, maintenance, etc., there is a demand for a coolant supply by an ordinary pump. One typical method to enable this is a right-angle nozzle method⁴⁾. As shown in **Fig. 3**, this method allows the coolant to be supplied perpendicular to the wheel surface, so that the coolant will break the air flow circulating with the rotating wheel and cling to the wheel surface to be guided to the grinding point. This method enables a low pressure pump to cope even with high wheel peripheral speed, while featuring simple nozzle installation position adjustment.

However, as this method uses one coolant nozzle with dual functions, i.e. breaking the air flow and supplying the required amount of coolant to the grinding point, a large amount of coolant is required. As a result, wheel spindle motor power loss, which is due to coolant contacting the wheel surface, increases. In particular as shown in **Fig. 4**, the higher the wheel peripheral speed, the greater the power loss.

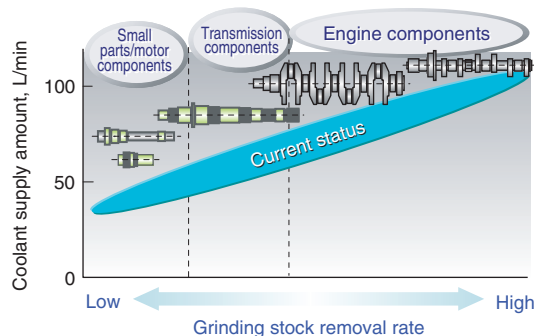


Fig. 1 Relation between the amount of coolant supply and target workpiece

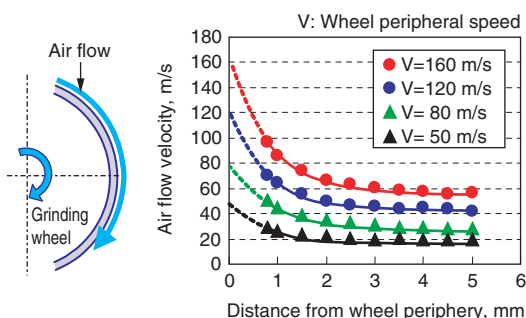


Fig. 2 Relation between wheel peripheral speed and air flow velocity

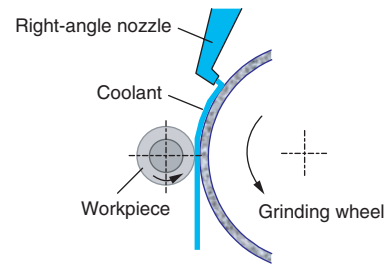


Fig. 3 Right-angle nozzle

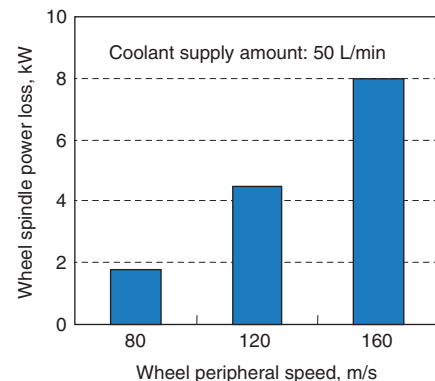


Fig. 4 Relation between wheel peripheral speed and wheel spindle power loss

3. New Coolant Supply System (ECOLOG Grinding TYPE II)

In order to overcome these issues, a new coolant supply system shown in **Fig. 5** has been invented. This new system is characterized by separating the two functions of conventional nozzle, "isolation of the airflow" and "supply of coolant to the grinding point". Specifically, the new system consists of an air supply provided above the grinding point from the side of the wheel to isolate the air flow, and a straight type nozzle oriented tangentially toward the wheel surface area near the grinding point to supply a small amount of coolant.

Figure 6 shows the CFD (Computational Fluid Dynamics) analysis results of the air flow velocity distribution when the air flow circulating around the rotating wheel outer periphery is blocked. From this figure, it is evident that in the new system, the air flow velocity in the vicinity of the wheel surface suddenly decreases immediately after air is supplied from the upper nozzle. In addition, because the layer of circulating air flow after isolation is thinner compared with the baffling plate method, it is thought that the coolant will reach the wheel surface more easily.

In order to confirm this effect, coolant was supplied to a wheel running at a wheel peripheral speed of 160 m/s, and the coolant supply state was compared between when there was air flow isolation and when there was not. Here, assuming that the velocity energy of the air is converted

into pressure at the grinding point, the coolant flow velocity required to break the air flow must have a flow velocity that generates higher pressure than the above assumed pressure⁵⁾. Based on this, the coolant supply conditions for this experiment were set to a pressure of 0.1 MPa and a flow rate of 3 L/min, where the coolant will not reach the wheel according to the calculation. It was confirmed, as shown in **Fig. 7 (a)**, that the coolant does not reach the wheel surface without air flow isolation. Air flow isolation by this new method enabled the air flow velocity in the vicinity of the wheel surface to be reduced by approx. 48%, which was measured actually with a pitot tube. As shown in **Fig. 7 (b)**, the coolant could reach the wheel surface even with the same coolant supply conditions. The description of the grinding performance and practical application will be explained hereafter.

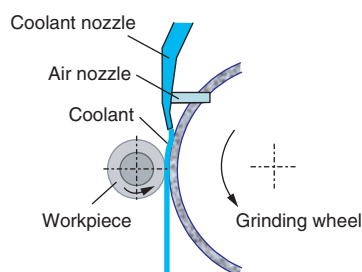
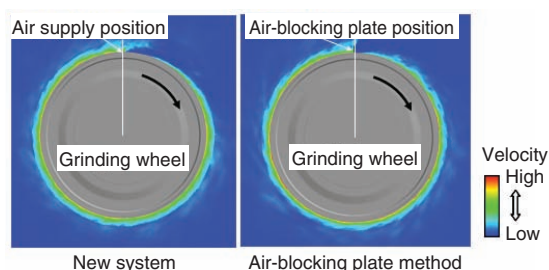


Fig. 5 New coolant supply system



Results of fluid analysis by TOYOTA CENTRAL R&D LABS., INC.

Fig. 6 Distribution of air flow velocity around wheel

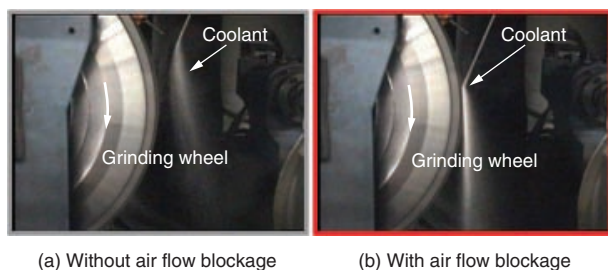


Fig. 7 Comparison of coolant supply state

4. Grinding Performance Evaluation Test

To evaluate grinding performance with the new coolant supply system, a grinding test was conducted using a cylindrical grinder. **Table 1** shows the grinding conditions. The test used a vitrified CBN grinding wheel to plunge grind a cylindrical workpiece made of carburized quenched chrome-molybdenum steel at a wheel peripheral speed of 120 m/s. This result was compared with the right-angle nozzle coolant supply system. Here, in order to clarify the thermal damage on the workpiece caused by the reduction in coolant supply, grinding cycle was stopped at rough grinding without spark-out. Maximum grinding stock removal rate was compared, based on the existence of hardness reduction due to grinding burn. **Figure 8** shows the relationship between the amount of coolant and the maximum grinding stock removal rate.

Table 1 Grinding conditions

Grinding wheel	Vitrified CBN grinding wheel ($\phi 400 \times 20\text{mm}$, #120, Concentration: 150)
Wheel peripheral speed	120 m/s
Workpiece	Chrome-molybdenum steel ($\phi 30 \times 20\text{mm}$) (Carburized quenched: 60HRC)
Workpiece rotational speed	150 min ⁻¹
Grinding method	Cylindrical plunge (Without spark-out)
Stock removal	$\phi 0.5\text{mm}$
Coolant	Emulsion type (Dilution rate: $\times 20$)
Air flow amount	150 NL/min

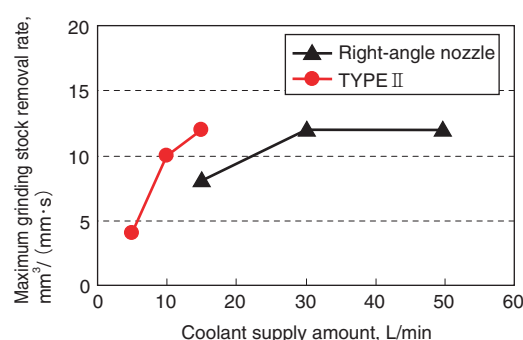


Fig. 8 Relation between the coolant supply amount and maximum grinding stock removal rate

Compared with the same coolant supply of 15 L/min, the new coolant supply system achieved a higher maximum grinding stock removal rate than that of the right-angle nozzle system. Also when a comparison was made with the same maximum grinding stock removal rate, the new coolant system was found to require less coolant supply. As a result, there was also less wheel

spindle power loss caused by coolant supply with the new coolant supply system than with the right-angle nozzle system. Furthermore, a continuous grinding test resulted in less coolant scattering, and thereby less grinding sludge accumulation on various parts of the machine.

5. Application to Crankshaft Pin Grinding

The grinding of crankshaft pins with significant eccentricity to the journal part is generally conducted with either of two methods, as shown in Fig. 9, that is, grinding while rotating around the center of the pin, by fixing the crankshaft at both ends by eccentric chucks or grinding while rotating the crankshaft in the journal center, and synchronizing the rotation of the eccentric pin part (C-axis) and wheelhead feed (X-axis) (hereinafter referred to as C-X grinding).

In recent years, the C-X grinding method which is flexibly adaptable to process integration or process separation is gradually becoming the mainstream production method. In this grinding method, however, because the grinding point moves up and down by a distance the same as the eccentricity, it is necessary for coolant nozzle to be located far above the grinding point to prevent possible interference with the workpiece. Therefore, the grinding point becomes less liable to receive coolant. Particularly, when the grinding point is lower than the journal rotation center, grinding burn due to an insufficient coolant supply becomes a problem. Thus, in the C-X grinding method, the amount of coolant supply tends to be increased.

However, it is found that when the new coolant supply system is used, coolant adheres down to the lower part of the wheel surface as shown in Fig. 10 even with a small amount of coolant. We therefore studied how well the

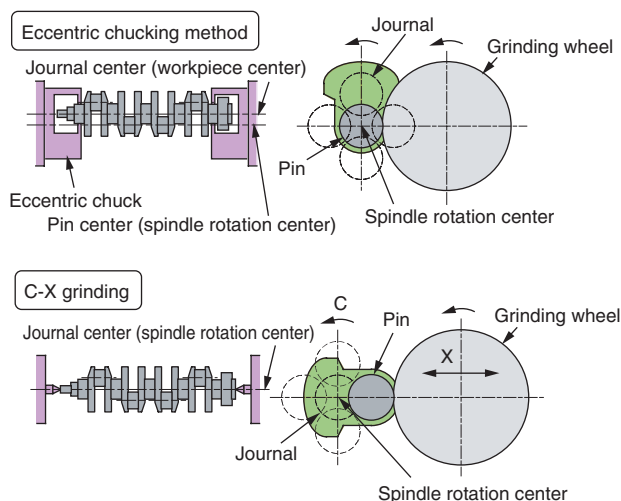


Fig. 9 Mechanism of crankshaft pin grinding

coolant reached the upper and lower parts of the wheel when the new coolant supply system was applied to the C-X grinding method. To evaluate the amount of coolant supplied to the actual grinding point, hydrodynamic bearing principle was applied on the arc⁶⁾ to measure the pressure at the grinding point, and this pressure was compared as an reference. Measurement, as shown in Fig. 11, was performed using a hole of $\phi 0.7\text{mm}$ on the

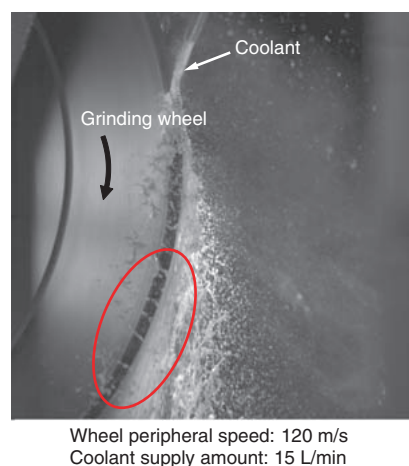


Fig. 10 Coolant supply state (cylindrical grinder)

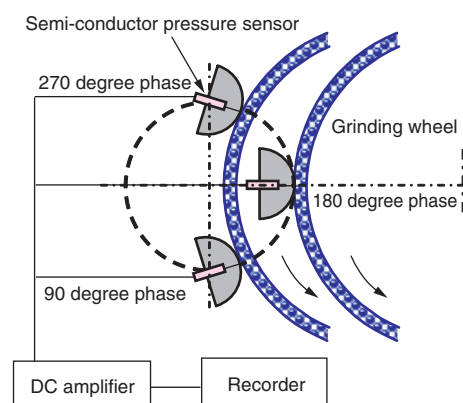


Fig. 11 Coolant pressure measuring method

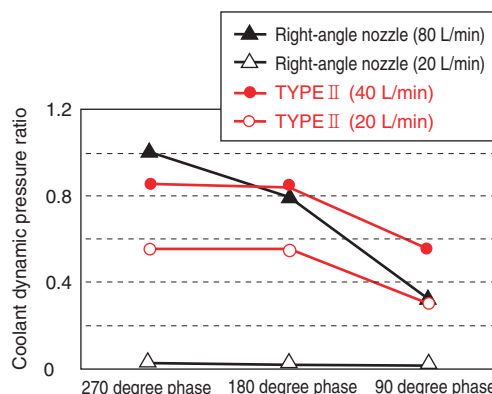


Fig. 12 Relation between pin phase and coolant pressure

periphery and a semi-conductor pressure sensor installed behind the hole. At a wheel peripheral speed of 120 m/s, when the coolant supply amount was changed, the coolant dynamic pressure generated at the grinding point of each pin phase was evaluated. The measurement results are shown in **Fig. 12**.

As shown in the figure, in the case of coolant supply of 80 L/min by the right-angle nozzle, while high coolant dynamic pressure was generated at the 270 degree phase which is the closest point to the coolant nozzle, there is a tendency for coolant pressure to decline substantially when the grinding point moves to the lower side. In contrast to this, even when coolant supply was halved to 40 L/min, the new coolant supply system showed only a small decline in coolant dynamic pressure with the grinding point moved, resulting in higher coolant dynamic pressure at the lowest 90 degree phase than experienced with the right-angle nozzle. Also, even only with 20 L/min, generation of equivalent dynamic pressure was observed, indicating the efficient supply of coolant.

Figure 13 shows a comparison of coolant supply states with and without isolating air flow around the wheel in an actual grinding operation at a wheel peripheral speed of 120 m/s. In this test, a test piece simulating the shape of a crankshaft pin was used for better observation. From the figure, the isolation of air flow has been confirmed to have reduced the scatter of coolant before reaching the grinding point, resulting in less sparks during grinding, even with low coolant supply of 20 L/min.

From the above, the new coolant supply system is considered to be effective in the C-X grinding method not only in the reduction of the amount of coolant supply, but also in the improvement of grinding performance such as the restriction of grinding burn.

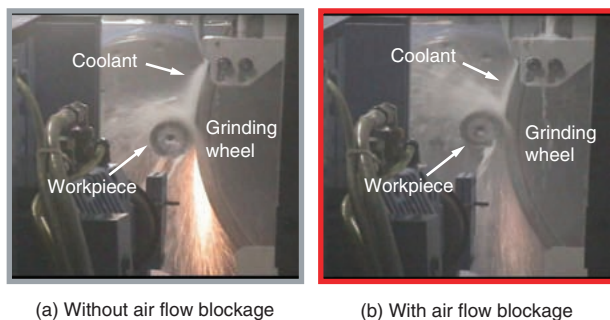


Fig. 13 Comparison of grinding states

6. Conclusion

The new coolant supply system (ECOLOG grinding TYPE II), in the high efficiency grinding operation realm, was found to be successful in reducing the coolant supply by 1/2 as well as in reducing the wheel spindle power loss by 1/2, with the same grinding performance as that of the conventional system. In addition, it was confirmed that in a grinding system where the grinding point moves up and down substantially like that for crankshaft pins, the new coolant supply system enables coolant to reach a lower position than the conventional system without a coolant nozzle following mechanism, and then this was applied to actual machines. As a result of these achievements, JTEKT received Technology Awards from the Japan Society for Precision Engineering and Japanese Society of Tribologists^{7), 8)}.

We will continue efforts to develop machining technology and grinding machines that are even more environment-friendly in order to meet both productivity and cost requirements as a total system.

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