High Productivity Dry Hobbing System

Takahide Tokawa*1      Yukihisa Nishimura*1
Yozo Nakamura*1

Conventional hobbing requires coolant, whose use complicates the work process and whose disposal endangers the environment. Dry hobbing requires a hob that can be used without coolant and a hobbing machine that discharges chips. We developed a hob of high-speed steel having a proprietary TiAlN coating and a dry hobbing machine to realize hobbing that is environmentally friendly and cuts total hobbing cost 34%, doubles cutting speed, extends tool life 5 times, and reduces electricity cost 51%.

1. Introduction

One of the largest present issues in machining shops is the coolant for lubricating and cooling tools. The coolant pollutes not only the working environment but also the global environment. Furthermore, in the hobbing described here as a typical gear cutting, coolant may additionally cause fires, i.e. it is a safety problem, because water-immiscible instead of water-miscible coolant is used. Under the circumstances, the development of a non-coolant based hobbing technique (hereafter termed dry cut hobbing) is strongly needed. Many machine tool manufacturers have so far developed dry hobbing techniques using carbide hobs. However, the carbide hobs are expensive and cause unexpected chipping, so that stable production cannot be maintained. Therefore, this type of dry hobbing has not yet been widely applied to practical production lines.

2. Problems related to coolants

Coolant has so far been considered to be one of the causes of working environment pollution as well as oil contamination in shops. Furthermore, recently its unfavorable influence upon the global environment has become an issue, burning waste oil causes dioxin emissions and acid rain due to chlorine contained in the coolant. In Europe, where environmental protection is rapidly advancing, it is said that the cost related to coolant accounts for 15 to 30% of machining cost[1], and also in Japan, it is considered that the coolant related costs will further raise machining costs.

Dry hobbing not only solves the above mentioned problems, it also eliminates the coolant cost, as well as the electricity costs for the cutting fluid circulatory system and mist collector become unnecessary and cost merits are newly produced.

3. Techniques aiming at dry cutting

Recently, various techniques aiming at dry cutting are being reported. For instance, cool air manufacturing using –30°C air instead of coolant blown at the machining point[2] or minimum quantity lubrication (MQL) where only several milliliters of coolant per hour is sprayed in a mist[3] are presented and are being partially commercialized for turning, end milling, and grinding. There is also a design where vegetable oil is used as coolant for achieving pollution-free machining.

Dry hobbing intended to be introduced here realizes an absolute dry hobbing without using any special devices.

4. Problems to be solved for dry hobbing

Themes for realizing dry hobbing are as follows:
(1) Development of a hob ensuring a stable tool life without coolant
(2) Development of a hobbing machine capable of discharging swarfs promptly without coolant

Absolute non-coolant dry hobbing cannot be realized until both a hob and a hobbing machine as shown above are developed. Therefore, in order to solve both problems, the tool and machine have been developed together.

5. Development of high-speed-steel hobs for dry cutting

5.1 Dry hobbing with conventional high-speed-steel hobs

The development of high-speed-steel hobs for dry cutting was started with dry cutting using conventional high-speed-steel hobs for wet cutting. The specifications of the workpieces, hobs and machining conditions are shown in Table 1. The cutting speed was set to be 200 m/min, i.e. twice the 100 m/min for conventional machining with coolant (hereafter termed wet cutting). The hob used had a TiCN PVD-coating on a high-speed-steel base material.

Fig. 1 shows the wear state of a hob after machining 26 parts without shifting the hob. The left flank is so severely worn that the tool life limit has been
The wear conditions after machining 26 workpieces using a conventional hob without shifting is shown. Abnormal wear is observed on the left tooth surface.

**Table 1 Conditions of test hobbing**

<table>
<thead>
<tr>
<th>Specifications of workpieces</th>
<th>Module</th>
<th>2.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of teeth</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Helix angle</td>
<td></td>
<td>21.5</td>
</tr>
<tr>
<td>Whole depth</td>
<td></td>
<td>6.5 mm</td>
</tr>
<tr>
<td>Face width</td>
<td></td>
<td>40 mm</td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td>SCM 415</td>
</tr>
<tr>
<td>Hardness</td>
<td></td>
<td>HB 170</td>
</tr>
<tr>
<td>Specifications of hobs</td>
<td>Outside diameter</td>
<td>φ 75 mm</td>
</tr>
<tr>
<td>Row number</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Gash number</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Machining conditions</td>
<td>Cutting speed</td>
<td>200 mm/min</td>
</tr>
<tr>
<td></td>
<td>Feed rate</td>
<td>2.4 mm/rev.</td>
</tr>
<tr>
<td></td>
<td>Cutting method</td>
<td>Same direction climb</td>
</tr>
</tbody>
</table>

![Fig. 1 Wear after dry hobbing with conventional hobs](image1.png)

The wear conditions after machining 26 workpieces using a conventional hob without shifting is shown. Abnormal wear is observed on the left tooth surface.

**Table 2 Application of super dry hob**

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>Cutting speed</th>
<th>Tool life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 → 200 m/min (44.9 → 29.9 s)</td>
<td>600 → 3 200 pieces (5.3 times)</td>
</tr>
<tr>
<td></td>
<td>90 → 200 m/min (47.4 → 31.2 s)</td>
<td>400 → 2 320 pieces (5.8 times)</td>
</tr>
</tbody>
</table>

![Fig. 2 Wear after dry hobbing with super dry hobs](image2.png)

The wear conditions after machining 26 workpieces using a super dry hob without shifting is shown. Abnormal wear is hardly observed.

The newly developed high-speed-steel dry cutting hob, termed “super dry hob,” has a special TiAlN composition lamina, which has excellent heat and wear resistance and can be PVD-coated onto the high-speed-steel base material for improved wear resistance.

**5.2 High-speed-steel dry cutting hob**

![Fig. 3 Wear after dry hobbing with super dry hobs](image3.png)

The wear conditions after machining 26 workpieces using a super dry hob without shifting is shown. Abnormal wear is hardly observed.

The above estimation has been verified in a practical production line. The results are shown in Table 2, which indicates that the tool life is more than 5 times the conventional life at the cutting speed of 200 m/min, double of a conventional hob.

Regarding machining precision, the machined surfaces were finished with a higher precision than that in wet cutting, with no scuffing observed.
The results that have so far been obtained are based on the hobs with coated cutting faces. Therefore, in order to maintain this state, re-coating is required after re-sharpening the hob.

The re-coating technique, which Mitsubishi Heavy Industries, Ltd. (MHI) has already established, ensures the high performance, double the machining speed and 5 times longer tool life. Furthermore, in the super dry hobbing, even if a resharpened tool is used without re-coating and with no coat on the cutting face, a tool life of more than 3 times can be achieved at the same machining speed as that in conventional wet cutting. The result is the performance largely exceeding that in conventional wet cutting.

5.3 Factors which realizes dry cutting

The reason why the TiAlN coating originated by MHI can make high-speed-steel hobs bear dry cutting at a cutting speed higher than that in wet cutting is thought to be associated partially with the properties of TiAlN.

Fig. 4 shows the result of the high-temperature oxidation test of TiN and TiAIN laminae.

The tests were carried out at 800°C for 5 hours in atmosphere. TiN was oxidized throughout the whole area of the lamina and changed into Ti oxide (TiO₂). On the other hand, the TiAIN oxidation is shallow, so that the properties are kept as they are, except for the very thin oxidized surface layer. The surface is changed into Al oxide (Al₂O₃). From this result, in dry cutting, the TiN lamina is rapidly worn because it deteriorates into TiO₂, which is low in hardness. On the other hand, high speed dry cutting makes the TiAIN lamina oxidize into Al₂O₃ at its surface, because TiAIN has a composition peculiar to MHI. Al₂O₃ has the merit that its hardness does not decrease at high temperatures. Although Al₂O₃ can be coated only by means of CVD, TiAIN can also be coated by means of PVD, keeping the same effect. The oxidation is limited to the surface, so that the lamina is not oxidized inside thus keeping adhesion. As a result, TiAIN is thought to show a high wear resistance during dry cutting.

6.Development of a dry hobbing machine

6.1 Problems of conventional hobbing machines

Most conventional wet hobbing machines are vertical. Dry hobbing machines using carbide hobs are also usually vertical, following the conventional machine configuration, so that flushing by coolant is required to discharge the swarf falling onto the machine beds.

Accordingly, in order to realize absolute dry cutting, the construction of hobbing machines was thoroughly reviewed.

6.2 Dry hobbing machines

Fig. 5 shows the developed dry hobbing machine. The configuration is changed from vertical to horizontal and under the machining part a large opening is provided so as to let the swarf fall by gravity through the opening. In the bottom of the opening, a chip conveyor is positioned to quickly discharge the falling chips to the outside.

In this way, chip disposal can be done without flushing coolant. Furthermore, since hot chips do not touch the bed, thermal deformation of the hobbing machine can be minimized.

As shown in Fig. 5, the height of the horizontal type can be decreased, making it shorter than the
vertical type (1340 → 1150 mm), therefore, it is basically rigid. However, since a large opening exists under the machining part for smooth chip disposal, a careful analysis of the bed rigidity was required. The rigidity was analyzed by the finite element method. The rigidities of the other parts besides the machine bed were also analyzed, so that dry hobbing machines having higher rigidity than those of conventional vertical hobbing machines were produced.

In order to cope with variously sized workpieces, three types were developed. These specifications are shown in Table 3.

### 7. Benefits of dry hobbing

Fig. 6 shows example trial estimations of the cost reductions by super dry hobs. A 34% cost reduction can be expected by the tool life extension, productivity improvement, and electricity savings. In machining most common automobile transmission gears, 37% of the energy is saved in comparison with conventional wet cutting. With wet cutting, besides a pump for the coolant circulation, coolant-related units such as the oil controller for cooling coolant heated by hot chips and a mist collector for recovering oil mist are necessary. Understandably, electric power consumption must be higher.

The super dry hobs have another merit, they save installation space and the machine is more compact because no coolant units are necessary.

Furthermore, dry hobbing has a cutting efficiency of about double that of conventional wet cutting, improving the productivity and reducing the required number of hobbing machines.

### 8. Examples of commercialized machines

Since the high productivity dry cutting system with the combination of the super dry hobs and the dry hobbing machines were first introduced to the world in October 1997, the system has attracted much user attention. As a result, the systems have already been operating in practical production lines both domestically and overseas.

During commercialization, chip disposal and increased work temperature sometimes caused
problems. In continuous machining with manual workpiece loading, the temperature increases were not observed in either workpieces or hobs, so that the over-ball diameter (OBD) variation was little and the $C_p$ (process capability factor) was as good as 3.067 over the tolerance of 40 µm. On the other hand, in continuous machining with automatic workpiece loading, the OBD variation was large and chip involvement sometimes occurred. Therefore, the air blow has been strengthened and chips have been positively removed to stabilize the machining precision and eliminate chip involvement problems, so that the tool life has been further extended.

9. Conclusions

The following results were obtained by the development of the dry hobbing techniques using high-speed-steel hobs.

(1) Dry cutting by means of high-speed-steel hobs, i.e. "super dry hobs" was commercialized for the first time in the world by developing MHI's special TiAlN-coat and the high-speed-steel base material specially used for it.

(2) Dry hobbing machines with coolant-free swarf discharge capability were developed.

(3) This combination of super dry hobs and dry hobbing machines realized the hobbing process with absolutely no coolant, improved working environment, and contributed to the improvement of the global environment.

(4) Cutting speed was largely increased, by two times and tool life was extended by five times.

(5) Since coolant-related units are eliminated, electricity was saved by 51%, so that the machining costs could be reduced by about 34%.

According to the above results, it can be said that the dry hobbing was developed as a system making the environmental improvement and the machining cost reduction compatible.

References

(1) Yokokawa, Kazuhiko et al., Cooling Air Cutting and Grinding Technology for Acquiring ISO 14000, Mechanical Engineering Vol.45, No.8 (1997) p.52
