Factors Affecting the Tooth Surface Finish of the Inner Gear Rings for Coal Cutters

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Abstract. In order to analyze the reason why tooth surface finish of the inner gear rings for coal cutters can not meet the standard requirement, a series of experimental studies are carried out on the gear-shaping cutter and the corresponding cutting parameters. It is found that the tooth surface finish can not reach the standard after machining with each cutting parameter by using a M2 high-speed steel cutter. Using a M42 high-speed steel cutter + Balchas coating, the tooth surface finish under each cutting parameter can meet the standard requirement. Combining with the requirements of machining efficiency and tooth surface finish, the matching cutting parameters are proposed. This study has guiding significance for improving the tooth surface finish of the inner gear rings for the coal cutters.

Keywords: Coal cutter; Inner gear ring; Gear-shaping cutter

1. Introduction

The inner gear rings are an important transmission part for the coal cutter. Their function is transmitting torque. High comprehensive performance and machining accuracy are required for the inner gear rings [1-2]. In order to ensure the smooth operation, low noise and long service life of the coal cutters, a well contact of the gears is needed. So, the tooth surface finish of the inner gear rings should be higher than Ra3.2. There are many researches investigating the processing technology, gear-shaping cutters and machining efficiency in terms of shaping the inner gear rings [3-7]. Most of these studies are based on high-end processing equipment and mass production. However, in some domestic enterprises with a low degree of digitalization, the common tooth profile processing method still occupies a dominant position. The gear-shaping cutters and cutting parameters are two important factors affecting the tooth surface finish of the inner gear rings. Therefore, it is necessary to study the effects of these two factors.

In the present study, the commonly used 42CrMo material with a hardness of 280-320 HB in our company is selected as tested materials. Different gear-shaping cutters and cutting parameters are compared to analyze the factors affecting the tooth surface finish of inner gear rings. Moreover, based on abovementioned researches, suitable gear-shaping cutters and corresponding cutting parameters are achieved.

2. Experimental Section

The cutting parameters include cutting speed, circumferential feed and radial feed. After the cutting speed is initially determined according to the tool strength (selected as V=12 m/min), the stroke number is determined according to the tooth width of the workpiece. The stroke length is 1.25 * 162 = 202 mm with a tooth having a length of 162 mm (MPD0108-09 M8Z64). The of stroke number is...
1000 * 12/203/2 = 31 times/min. The circumferential feed depends on the rigidity of the machine, and the maximum amount of circumferential feed \( F_{c_{\text{max}}} \) is calculated according to the following equation:

\[
F_{c_{\text{max}}} = F_{z_{\text{max}}} Z^{0.11} / 0.609 m^2
\]

Where \( F_{z_{\text{max}}} \) is the maximum cutting force of the machine, \( Z \) is the number of workpiece tooth, \( M \) is the workpiece modulus.

When the gear-shaping cutter makes a reciprocating movement, it also moves a certain distance to the center of the workpiece until the full height of the whole tooth is cut out. If the cutting is divided into \( K \) times, the radial feed \( T \) is calculated as \( H/K \), where \( H \) is the full height of the tooth.

In this study, the effects of various cutting parameters on the tooth surface finish of the inner gear rings for the coal cutters under M2 high-speed steel cutter and M42 + coated cutter are studied, respectively, which provides a basis for tool selection and determination of cutting parameters. The experimental specimens are m8z64 (MPD0108-09), and the tooth surface finish must reach \( \text{Ra}3.2 \). The experimental equipment is a Y5180 CNC gear shaper, and a roughness meter is used to detect the tooth surface finish.

3. Results and Discussion

Using M2 high-speed steel cutter by changing machining parameters, such as circumferential feed, cutting number and stroke number, their influences on tooth surface finish, tool life and machining efficiency are shown in Table 1. The tooth surfaces are shown in Figure 1. Thus, it can be known that when the circumferential feed increases from 0.45 mm/str to 0.5 mm/str, the tooth surface finish increases from Ra6.5 to Ra6.2, tool life remains unchanged, and the machining efficiency decreases. When the cutting number increases from 5 to 6, the tooth surface finish increases from Ra6.5 to Ra5.2, tool life remains unchanged, and the machining efficiency decreases. When the stroke number increases from 30 str/min to 40 str/min, the tooth surface finish increases from Ra6.5 to Ra5.4, tool life remains unchanged, and the machining efficiency decreases.

**Table 1.** Experimental results of changing single cutting parameters under M2 high-speed steel cutter.

| Cutting parameters  | Before Parameters | Before Finish | Before Tool life | After Parameters | After Finish | After Tool life | Efficiency  |
|---------------------|-------------------|--------------|-----------------|------------------|--------------|----------------|-------------|
| Circumferential feed| 0.45 mm/str       | Ra6.5        | 4               | 0.5 mm/str       | Ra6.2        | 4              | Reduce      |
| Cutting number      | 5                 | Ra6.5        | 4               | 6                | Ra5.2        | 4              | Reduce      |
| Stroke number       | 30 stroke/min     | Ra6.5        | 4               | 40 stroke/min    | Ra5.4        | 4              | Improve     |

**Figure 1.** Tooth surfaces of experimental results of changing single cutting parameters under M2 high-speed steel cutter: (a) increasing circumferential feed; (b) increasing cutting number; (c) increasing stroke number.
It can be seen that the tooth surface finish is reduced via increasing the abovementioned three parameters. However, there are still cutting marks and cutting tumors on the tooth surfaces, which can not meet the standard requirement. In order to consider the influence of the matching of machining parameters on the tooth surface finish, the three parameters are adjusted at the same time. After many tests, the final adjustment is that the circumferential feed is 0.5 mm/str, the cutting number is 6, and the stroke number is 35 str/min, which can reach the maximum finish of the tooth surface under M2 high-speed steel cutter, as shown in figure 2.

**Figure 2.** The maximum finish of the tooth surface under M2 high-speed steel cutter under parameter matching adjustment.

According to the analysis of the above test results, we can know that no matter how to adjust the machining parameters, using the M2 high-speed steel cutter can not meet the standard requirement of the tooth surface finish for the inner gear rings. So the following study is to change the tool material. An M42 high-speed steel cutter + Balchas coating is used, the chemical composition comparison of the two cutters is shown in table 2. Compared with M2 high-speed steel cutter, M42 high-speed steel cutter is a high-carbon cobalt super-hard high-speed steel, which is mainly used for fabricating precision cutting tools with high hardness, high wear resistance and high toughness. After heat treatment, the hardness is high, up to 67-70 HRC, the thermal hardness is good, the high-temperature hardness is high, and the blade is sharp [8-10]. Therefore, the comprehensive performance of the M42 high-speed steel cutter is better than that of the M2 high-speed steel cutter.

**Table 2.** Chemical compositions of M42 and M2 high-speed steel cutters.

|       | C   | Si  | Mn  | S   | P   | Cr  | Mo  | W   | V   | Co  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| **M42** | 1.05~ | 0.15~ | 0.15~ | ≤0.0 | ≤0.030 | 3.50~ | 9.00~ | 1.15~ | 0.95~ | 7.75~ |
| 1.15% | 0.65% | 0.40% | 30%  | %   | 4.25% | 10.00% | 1.85% | 1.35% | 8.75% |
| 0.78~ | 0.20~ | 0.15~ | ≤0.0 | ≤0.030 | 3.75~ | 4.50~ | 5.50~ | 1.75~ | /    |
| **M2**  | 1.15% | 0.65% | 0.40% | 30%  | %   | 4.25% | 10.00% | 1.85% | 1.35% | 8.75% |
| 0.88% | 0.45% | 0.40% | 30%  | %   | 4.50% | 5.50% | 6.75% | 2.20% | /    |

Under the condition of M42 high-speed steel cutter + Balchas coating, the effects of conventional machining parameters, reducing circumferential feed, increasing cutting number and increasing stroke number on tooth surface finish and machining efficiency are shown in table 3. The corresponding tooth surfaces are shown in figure 3. As can be seen from table 3, because the comprehensive performance of the M42 high-speed steel cutter is better, the tooth surface finish under various machining parameters meets the standard requirement, that is, higher than Ra3.2. Under the conventional cutting parameters, the tooth surface finish reaches Ra2.3. When the circumferential feed decreases from 0.45 mm/str to 0.40 mm/str, the finish increases from Ra2.3 to Ra2.19, but the machining efficiency decreases. When the cutting number increases from 5 to 6, the tooth surface finish increases from Ra2.3 to Ra2.03, and the machining efficiency also decreases. When the stroke
number increases from 30 str/min to 45 str/min, the tooth surface finish decreases from Ra2.3 to Ra2.6, but the machining efficiency improves. According to the experimental results, the matching adjustment is carried out. Although the smoothness is reduced to Ra2.9, the machining efficiency is significantly improved.

According to the above studies, in order to improve the machining efficiency under the premise of satisfying the tooth surface finish, the matching cutting parameters are obtained in the present study, that is, the amount of circumferential feed is 0.45 mm/str, the number of stroke is in the range of 30–45 str/min, the times of cutting remains the same, still 5 times.

**Table 3.** Experimental results of changing cutting parameters using M42 high-speed steel cutter + Balchas coating.

| Method                | Circumferential feed | Cutting number | Stroke number | Finish | Efficiency |
|-----------------------|----------------------|----------------|---------------|--------|------------|
| 1 General parameter  | 0.45 mm/str          | 5              | 30 str/min    | Ra2.3  | Reduce     |
| Reduce circumferential feed | 0.40 mm/str      | 5              | 30 str/min    | Ra2.19 | Reduce     |
| 2 Increase cutting number | 0.45 mm/str       | 6              | 30 str/min    | Ra2.03 | Reduce     |
| 3 Increase stroke number | 0.45 mm/str        | 5              | 45 str/min    | Ra2.6  | Improve    |
| 4 Matching adjustment | 0.50 mm/str          | 5              | 40 str/min    | Ra2.9  | Improve    |

**Figure 3.** Tooth surface finish of inner gear rings of changing single cutting parameters under M42 high-speed steel cutter + Balcha conditions: (a) conventional parameters; (b) reducing circumferential
feed; (c) increasing cutting number; (d) increasing stroke number; (e) matching adjustment.

4. Conclusions
To solve the problem that the tooth surface finish of the inner gear ring for coal cutter can not meet the standard requirement under the common tooth profile machining mode, this paper studies in detail the influence of the machining parameters on the tooth surface finish adjusted by M2 high-speed steel cutter and M42 high-speed steel cutter + Barchas coating, in order to provide experimental parameters for tool selection and matching machining parameters. The main conclusions are as follows:

(1) Using M2 high-speed steel cutter for cutting, after optimizing the parameters, the tooth surface finish can only be optimized to Ra4.4, which can not meet the standard requirement of Ra3.2.

(2) After using M42 high-speed steel cutter + Barchas coating with good thermal hardness and high temperature hardness, the tooth surface finish under each parameter can meet the standard requirement. Therefore, this kind of cutter should be used to process the inner gear ring. Considering machining efficiency, the matching cutting parameters are determined as the circumferential feed is 0.45 mm/min, the stroke number is 30-45 str/min, and the cutting number is 5 times.

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