

5 TITLE OF THE INVENTION

SPHERICAL CUTTING TOOL

FIELD OF THE INVENTION

10 The present invention relates to spherical rotary cutting tools (also be called spherical cutting tools) such as ball end mills, tapered ball end mills and the like, in which cutting edges are formed on a spherical surface.

15 Particularly, the present invention relates to the cutting edges with constant helix angle on the spherical surface. As a natural consequence, it improves the cutting performance, the chip disposal and the surface roughness of the material to be cut. Also, the cutting edges could be formed with the eccentric relief on the
20 land, provided the helix angle is constant; the tooth formed by the eccentric relief is reinforced with a smaller relief angle and a wider land width. And therefore, the tool can be operated at the higher feed rate, thereby making it possible to improve the machining efficiency.

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BACKGROUND OF THE INVENTION

As shown in FIG.1, the cutting edges of the conventional spherical
30 cutting tool like the ball end mill consist of a part of spherical cutting edges (also to be called spherical edge) and a body with peripheral cutting edges (also to be called peripheral edge). The spherical edge serves as the main cutting

edge, while the peripheral cutting edge serves as auxiliary cutting edge.

In the case of cylindrical cutting tools like the square end mills where the main cutting edges are formed on the periphery, the cutting edge has a constant helix angle relative to the tool axis. Thus by providing a proper helix angle to the cutting conditions, the performance of the tool can be markedly improved. If a cutting tool has a constant helix angle, the lengths of the cutting edges are extended, and therefore, the cutting force per unit length is reduced. Further, the continuous cutting is taken place, and the impact is minimized during the cutting. Consequently, the surface roughness of the cut surface is made fine, a precise cutting is possible, and the life expectancy of the tool is extended. That is because the helix angle functions as the rake angle also, and therefore, in the case of a cylindrical cutting tool, 30 degrees of constant helix angle is recommended for steel cuttings, while 45 degrees for cutting aluminum and its alloys.

The helix angle is closely related to the lead and the tool diameter. As shown in FIG. 2, this relationship can be expressed by a formula $\tan H = \pi D/L$, where H is the helix angle, L is the lead, and D is the diameter of the tool. In the peripheral cutting edges of the spherical tool or in the main cutting edges of the cylindrical tool, if the lead is fixed, the helix H has a constant value, or an inverse case is realized. Therefore, the above advantages can be easily realized.

However, in spite of the fact that the performance of the tools can be significantly improved by providing a constant helix of a certain angle, there has not been appeared any such tool in which the spherical cutting edges have a certain constant helix angle relative to the tool axis. But only the cutting edges are arranged on the spherical surface in such a manner as to be blended well to the peripheral cutting edges, but without any coherent relationship or law. The examples are the curves (1), (2), (3) and (4) of FIG. 3. This is due to a fact described below.

That is, each cross section of the cylinder has the same diameter regardless of axial positions, while in a sphere the diameter of each cross section is varied along the axial positions (FIG. 4). Owing to this
5 characteristic, even if the lead is decided, the tool diameter is varied along the tool axis, and therefore, the helix angle H which is based on the formula $\tan H = \pi D/L$ has to have a different value at each position. As a result, a constant helix angle cannot be expected.

10 Meanwhile, if any curve being on a sphere which connects two points intersecting the tool axis and the surface of sphere is rotated around the tool axis, the track forms a sphere as shown in FIG. 5. Therefore, if cutting edges are arranged on a sphere regardless of the shape and constancy of the helix angle, and if a rotary cutting is carried out with this tool, then there is formed a
15 concave sphere with the same size of the sphere on the tool. This fact seems to make the demand for the spherical cutting tools with constant helix lighten. That is, even if the efficiency and performance are poor, the designed shape can be produced, and therefore, the above tool is not urgently required. Therefore, the conventional spherical cutting tools such as ball end mills were
20 far inferior in their performance to the cylindrical cutting tools having a constant helix angle like in the square end mills.

SUMMARY OF THE INVENTION

25 The present invention is intended to overcome the above described disadvantages of the conventional tools by modifying the contour of the cutting edges.

Therefore it is an object of the present invention to provide a
30 spherical cutting tool in which the conventional disadvantages are overcome by arranging the geometrical points of the cutting edges or their tracks.

In achieving the above object, the spherical cutting tool according to the present invention is characterized in that the tangential lines of the respective points of the cutting edges on a spherical surface are made to have a constant angle relative to the axis of the tool, and thus, a machining efficiency is realized in the main cutting edges of the spherical cutting tool like in the main cutting edges of the cylindrical cutting tool.

Further, in achieving the above object, the spherical cutting tool according to the present invention is characterized in that the cutting edges are disposed on a spherical surface, and the helix angle of the cutting edges is constant at any position on the spherical surface.

Further, based on the constant helix angle on the spherical surface, the tooth should preferably have a wider land with a smaller relief angle.

Further, the tooth should be made of a material same as that of the tool body.

Further, the tooth made of a super hard alloy metal or a high speed tool steel may be bonded to the steel body by brazing or by a mechanical means.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and other advantages of the present invention will become more apparent by describing in detail the preferred embodiment of the present invention with reference to the attached drawings in which:

FIG. 1 illustrates the conventional spherical cutting tool;

FIG. 2 illustrates the relationship between the helix angle, the lead and the tool diameter in the conventional cylindrical cutting tool;

FIG. 3 illustrates examples of the positioning of the cutting edge in the conventional spherical cutting tool, in which an edge is disposed with a constant helix angle of 30 degrees;

FIG. 4 illustrates the fact that the diameter of the spherical cutting tool is varied along the axis of the tool;

FIG. 5 illustrates the fact that a spherical body rotates, any curve on the spherical surface draws a sphere;

FIG. 6 illustrates the relationship between the sphere central angle, the axis rotational angle and the helix angle, when the constant helix is formed on the spherical surface according to the present invention;

FIG. 7 is a front view showing the contour of the peripheral edges of the end mills, in which:

FIG. 7a illustrates the conventional concave relief contour;

FIG. 7b illustrates the conventional flat relief contour; and

FIG. 7c illustrates the eccentric relief contour which is applicable to the spherical edges according to the present invention; and

FIG. 8 is a comparison between the contour of the central tooth and the object to be machined, in which:

FIG. 8a illustrates the contour by the central tooth with flat relief of the conventional square end mill;

FIG. 8b illustrates the contour by the central tooth with concave relief of the conventional spherical cutting tool; and

FIG. 8c illustrates the possible contour by the central tooth with eccentric relief of the spherical cutting tool according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Now the present invention will be described in detail in such a manner that those ordinarily skilled in the art can carry out the present invention.

FIG. 6 illustrates the relationship between the sphere central angle, the axis rotational angle and the helix angle, when the constant helix is formed on the spherical surface according to the present invention.

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The spherical cutting tool according to the present invention is constituted such that a hemisphere and a cylinder with the same radius r are combined together across a virtual boundary face. Now it is assumed that an arbitrary curve is drawn in the spherical surface. Further, the crossing point
10 between the virtual boundary face and the curve will be called "starting point of the curve on the spherical surface", and a virtual plane which covers the starting point of the curve and the axis of the combined body will be called "reference plane". Further, the angle between the reference plane and the radial line of a certain point on the arbitrary curve will be called "axial
15 rotational angle y ". Further, the angle between the virtual boundary face and the radial line of a certain point on the arbitrary curve will be called "sphere central angle β ". Then an arbitrary position can be expressed by r, β and y .

When defining the relationship between r, β and y , the present inventor
20 found the fact that y and β are mutually subordinate through " $\tan H$ ", when the points on the cutting edges maintain a constant helix angle H . That is, he found the relationship " $y = \beta * \tan H$ ".

In other words, it is assumed that the cutting edges are disposed
25 at " $\beta * \tan H$ " from the reference plane with a sphere central angle of β ($\beta = 0$ to 90 degrees). Then the tooth have a perfectly constant helix angle of H degrees. That is, when the helix angle is decided suitably to the use of the tool, the axial rotational angle can be calculated based on a formula in which the $\tan$ value of helix angle is a constant, and the sphere central angle β is
30 a variable. Then, connecting the cross points by a line, the curves, i.e., the cutting edges with the predetermined constant helix angle will be obtained. As

an example, the track of a helix angle of 30 degrees is illustrated in FIG. 3.

In view of the formula " $\gamma = \beta \cdot \tan H$ ", the factors for obtaining a constant helix angle are not related to r at all. This is a feature which is quite different from the fact that the helix angle of the conventional cylindrical tool is directly governed by the tool diameter D , i. e., $2r$. In the spherical cutting tool having a certain constant helix angle, producing and/or regrindings are possible with a cam in the mechanical machine or a program in the numeric-controlled machine regardless of the size of the tool diameter. Further, the edges have a fixed relationship with r , β and γ , and therefore, they can be easily disposed on the spherical surface.

One of the essential advantages which can be obtained from the constancy of the helix angle is as follows. That is, the tooth could be formed with the eccentric relief. The conventional spherical cutting tools have either concave relief or flat relief (which is abnormal).

In this conventional case, in order to maintain the functions of the clearance, either the land width has to be made narrower, or the relief angle has to be increased. With the result, the strength of the tooth is weakened. This problem becomes more serious as the tool diameter is smaller, and as it approaches the tool axis.

Accordingly, the conventional spherical cutting tool cannot be operated at a higher feed rate. The eccentric relief which has solved the conventional problems of the concave and flat forms is governed by the following relations. That is, it is governed by a formula $\tan S = \tan R / \cos H$, or $\tan S = \tan R \cdot \tan H$, where R is the relief angle, and S is the setting angle. If the helix angle is different at every position on a cutting edge, then the setting angle has to be varied accordingly, but this is actually impossible. On the other hand, if the cutting edges have a constant helix angle, then the tooth

can be formed with eccentric relief, in a state with the setting angle fixed. In this case, the tooth can be reinforced with a relatively small relief angle and a wide land width. Therefore, the tool can be operated at a higher feed rate, thereby improving the machining efficiency.

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Further, the tooth made of a super hard alloy metal or a high speed tool steel may be bonded to the steel body by brazing or by a mechanical means.

In the present invention, the constant angle refers to the fact that
10 the same magnitude of angle is realized at any point on the cutting edges. The lead refers to the advancing distance of the cutting edge in the axial direction during one rotation of the tool having the helical cutting edges. Further, the tool diameter refers to the distance of a line passing through the center of the circumference of the tool and ending at two points on the circumference.
15 Further, as a conception same as the helix, the spiral refers to curve which are formed in the form of a vortex on a cone or on a spherical surface. The angle between the spiral and the tool axis is called "spiral angle". Thus, in some cases, "spiral angle" is distinguished from the helix angle, but in the present invention, the spiral angle and the helix angle are made to have the
20 same meaning.

In the above, the present invention was described based on the specific preferred embodiment, but it should be apparent to those ordinarily skilled in the art that various changes and modifications can be added without departing
25 from the spirit and scope of the present invention.

According to the present invention as described above, the cutting edges have a constant helix angle, and the tooth is formed with the eccentric relief. Therefore, the teeth are reinforced with a relatively small relief angle
30 and a wide land width, so that the tool can be operated at a higher feed rate, thereby improving the machining efficiency.

WHAT IS CLAIMED IS:

1. A spherical cutting tool characterized in that: cutting edges are disposed on a spherical surface; and said cutting edges have a constant helix
5 angle at any point of said cutting edges.
2. The spherical cutting tool as claimed in claim 1, wherein a tooth on said tool has a smaller relief angle and a wider land width based on the constant helix angle.
- 10 3. The spherical cutting tool as claimed in any one of claims 1 and 2, wherein teeth are made of a material same as that of a tool body.
4. The spherical cutting tool as claimed in any one of claims 1 and
15 2, wherein said teeth are made of a super hard tool material or a high speed tool steel, and said teeth are bonded to said tool body by brazing or by a mechanical means.

