

345. Tool edge geometry and wear recognition by means of a contact method

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Abstract. The aim of this paper is to present a device to measure non-destructively the geometry of cutting edges as well as to detect the wear. This might sound easy. One might propose a usual optical way where an edge is illuminated by an inclined beam and observed from the top. Another might try to use a surface roughness measurement device. However, those were all tested in the past and ended up with a total failure or severe limitation in application. The major reason consists in the size of roundness. For the case of a lancet or shaving knife the roundness is of the order of 2 – 5 μm and varies along the periphery covering over 300 degrees. This paper presents a non-destructive method, which consists of a mechanical device and software package for performing reading and mathematical calculations as well as obtaining practical knowledge on the relationship between the sharpness and performance of various sharp edges according to their purposes.

Keywords: tool-edge, non-destructive measurement.

Introduction

To make a sharp edge is one of the oldest technologies that human beings have ever developed in the last few hundred thousand years. Industries are now producing sharp edges for many industrial applications. The lancets for surgery, knives, shavers, cutting tools for machining metals, etc., all have sharp edges. However, the sharpness and wear of the edge are not measured when those edges are produced in industry. The reason is that there is no practical device to measure on-line.

Current methods, which describe the wear-out or sharpness of cutting tools, are not sufficiently accurate, are destructive and cannot be operated online. For example, let us review a few methods that have been already tested in the past:

1. The edge of the knife is observed under a microscope and only its cross-section is measured. This method is destructive and the accuracy is limited.

2. In the second method, a plastic replica is made and the cross section of that replica is measured. This method is non-destructive but it is a time-consuming offline scheme and its accuracy is even lower.
3. Another method estimates the area of contact at the edge by measuring the electrical resistance. This method is fast though offline but the accuracy is very poor.
4. The most accurate of these methods is that of using either a scanning probe microscope or an atomic force microscope, but this is a time-consuming offline scheme and more than that - the device itself is very expensive.

However, the aforementioned methods are either destructive or time-consuming and are not applicable to production lines. The purpose of this paper is to develop a device for non-destructive measurement of the sharpness of the cutting tool-edge.

The working principle of the proposed method

A prototype of the proposed method is shown schematically in Fig. 1. The tool-edge to be measured is locked in a special gripping device. And the measurement lever is applied from one side of the edged tool. The end of the lever is fixed and it can rotate 360°. The lever is placed on the blade of the measured tool and is turned by moving the model up and down in the vertical position.

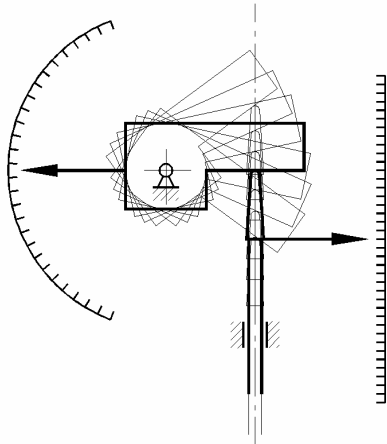


Fig. 1. Proposed prototype

The device was developed earlier for testing the method of measuring of the tool-edge geometry [1-3]. But additional modifications were done in order to improve reading of measurements. For example, a linear encoder for longitudinal motion was attached.

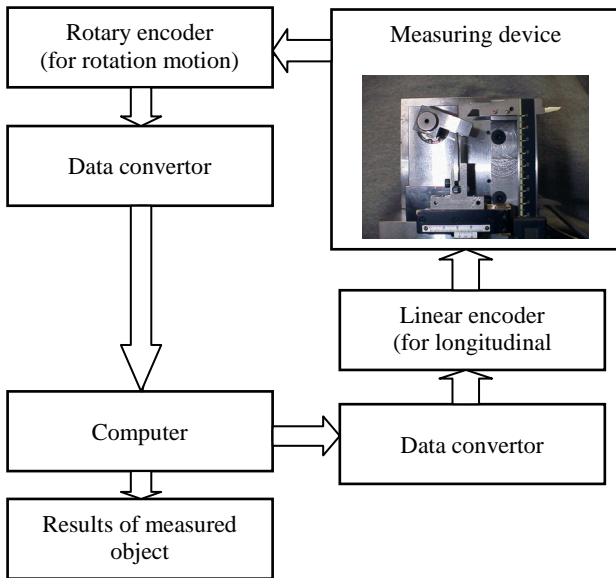


Fig. 2. Measuring structure

The motion of the lever and gripping device are controlled by two installed rotary encoders through data converters by computer (Fig. 2). Movements are measured up to 5 mm in height by moving it up and down by 0.1 mm, later from 5 to 15 mm in height by 0.2 mm, and the

rest, if needed, is carried out by moving up and down by 1 mm.

The principle of measuring

The principle of this system is to reconstruct the edge shape by its envelope lines. The tool-edge is moved up and down and the metal lever moves accordingly around its rotation center.

The aim of the method is to detect a change in the angle of the lever, which forms tangent line above the edge at a point of touch. Tangent lines form and envelope the shape of the tool-edge. Figure 3 shows how this is accomplished.

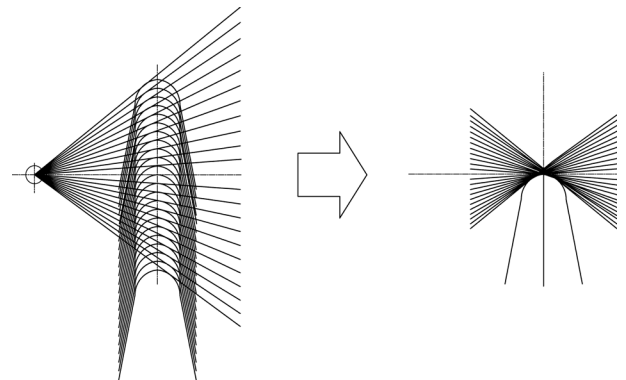


Fig. 3. Shape formation

Figure 4 shows the position of tool measurement by moving it up and down. From the rotation angles α and β of the lever and the height h movement of the tool edge it is possible to draw an envelope as illustrated in Figure 3.

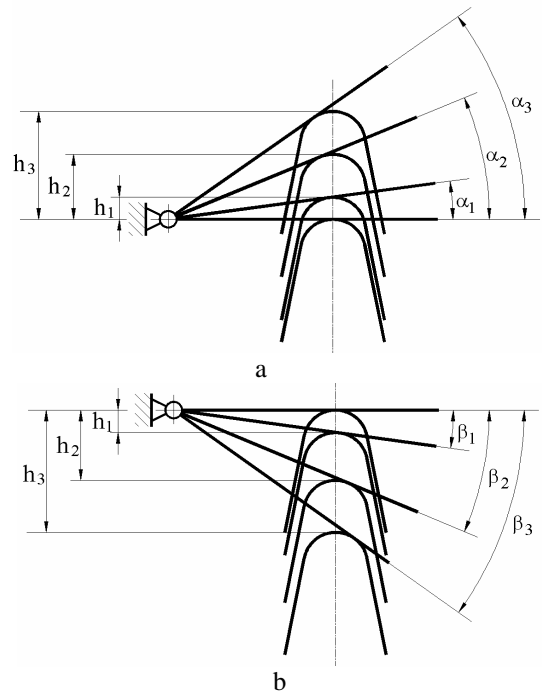


Fig. 4. Measurement: a) right side of tool, b) left side of tool

In order to reconstruct the shape of the edge as an envelope line, the following calculation is needed.

The inner envelope line obtained by a set of tangent lines should give us the shape of measured edge, which can be expressed in this way:

$$y=x \tan \alpha \text{ or } y=x \tan \beta \tag{1}$$

After rotation angle α and β the movement height h is read accordingly to the movement of an object by a linear encoder. By using this data the tangent line of the metal strip at the touch point with measured object is drawn. By drawing all these lines, an envelope shape is formed.

The data of the shape are obtained by reading every cross point between two tangential lines.

For example, the first point will be found from the following equation system:

$$\begin{cases} y = x \tan \alpha_1 x - h_1 \\ y = x \tan \alpha_2 x - h_2 \end{cases} \text{ or } \begin{cases} y = x \tan \beta_1 - h_1 \\ y = x \tan \beta_2 - h_2 \end{cases}$$

the second one from this:

$$\begin{cases} y = x \tan \alpha_2 x - h_2 \\ y = x \tan \alpha_3 x - h_3 \end{cases} \text{ or } \begin{cases} y = x \tan \beta_2 - h_2 \\ y = x \tan \beta_3 - h_3 \end{cases}$$

etc.

Or it can be expressed in this way:

$$\begin{cases} y = x \tan \alpha_{n-1} + h_{n-1} \\ y = x \tan \alpha_n + h_n \end{cases} \text{ or } \begin{cases} y = x \tan \beta_{n-1} + h_{n-1} \\ y = x \tan \beta_n + h_n \end{cases} \tag{2}$$

These points are formatting our measured shape of the object (Fig. 5). To express it, a linear function of the order of six degrees is used,

$$y = 1 + ax + ax^2 + ax^3 + ax^4 + ax^5 + ax^6.$$

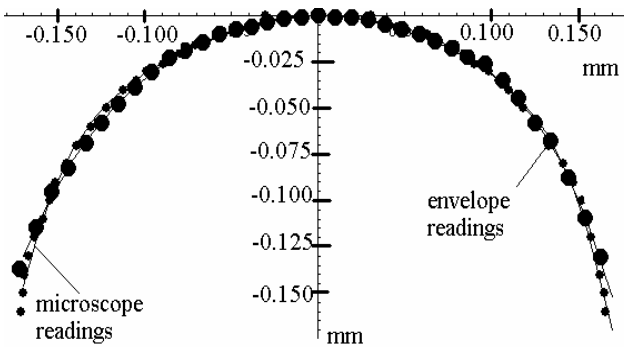


Fig. 5. The shape of the tool-edge with the radius of 0.150 mm

Results

Experiments were carried out using model-edges, which were made in different radius from 0.040 mm to 2.00 mm, and new or used indexable inserts in order to test the capability of this method. Figure 6 demonstrates the cross-sections of an indexable insert. In the experiment we also used the inserts of a conventional metal cutting tool, some of them were coated with diamond-like carbon coating. Also some of inserts were measured after they had been used in actual process.

Straight tangent lines, obtained from the measured data by calculation, form the envelope, which is depicted in Fig. 3. The obtained results from the envelope readings were compared with microscope readings (Fig. 5). Both curves of microscope reading and envelope were expressed by the 6th power linear function.

$$f = \sum_{n=1}^6 a_n x^n \tag{3}$$

This curve fitting was performed in the effective width, within which measurement could be carried out effectively. To express the degree of fitness between two readings some calculations were carried out by introducing a measure named 'normalized error'.

By using this function we are comparing our result with the microscope reading of the cross-section of the measured object in the limits of effective width. Later we will find an average of distribution of this error.

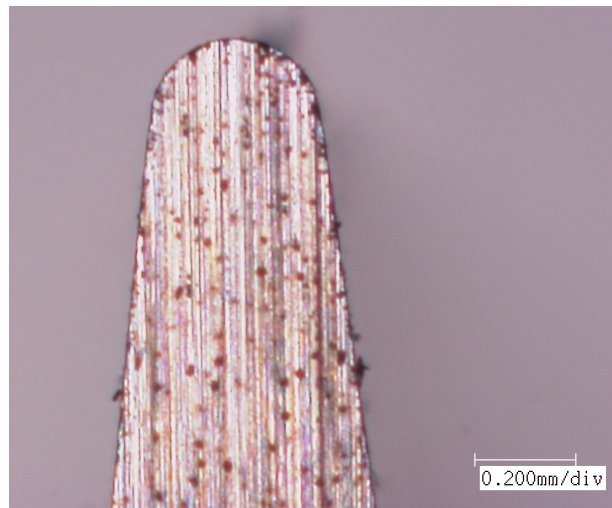


Fig. 6. The model edge with the radius of 0.150 mm

The normalized error is expressed as an integration of deviation of envelope reading from microscope reading (eq. 4). The normalized error is obtainable only in the range of the effective width. The effective width is limited by the rotation angle of the tool-edge.

$$\varepsilon_e = \frac{E_{total}}{L2 - L1} = \frac{\int_{L1}^{L2} |f_e - f_m| dx}{L2 - L1} \tag{4}$$

where $L1$ and $L2$ are the values of x - axis at the limits of edge rotation to the left and right respectively, (in other words the effective width); and f_e and f_m are the linear functions of the shapes obtained by envelope and microscope readings, respectively.

Effective width is the length of the measured object shape, and it is described by the rotation angle of the metal strip. Effective width is not a constant value; it even varies for the same shape if it was moved in the system. Effective width is found by deviation of the linear function mentioned above.

$$\frac{d(1 + ax + ax^2 + ax^3 + ax^4 + ax^5 + ax^6)}{dx} = \tan \beta \tag{5}$$

In our experiments we have tested various models and inserts. Measurement results are listed in Table 1.

It may be noticed in Table 1 that the accuracy of this method is on the level of 0.45-5 μm for the cases of model-edges and of 2-4 μm for the case of inserts of metal cutting tools. This level is the maximum accuracy attainable at this stage. In order to evaluate the accuracy of the proposed method, the following measures were introduced and the result given in the Table 1 was obtained. Table 1 indicates that the accuracy of this method is on the level of 0.4-5.0 μm for the cases of model-edges and of 1.9-3.0 μm for the case of inserts of metal cutting tools. This level was improved and attained after using additional linear motor for vertical motion of the measured edge movement.

Table 1. Results

Measured object	Normalized error, μm
Model - edge $R \approx 2.000$ mm	4.58
Model - edge $R \approx 1.000$ mm	1.93
Model - edge $R \approx 0.500$ mm	1.19
Model - edge $R \approx 0.250$ mm	0.62
Model - edge $R \approx 0.150$ mm	0.58
Model - edge $R \approx 0.075$ mm	0.42
Model - edge $R \approx 0.040$ mm	0.92
Insert Nr.1	1.95
Insert Nr.2	2.19
Insert Nr.3	2.87
Insert Nr.4	2.70

Furthermore, by applying some mathematical calculations it is possible to calculate the radius of the tool-edge. It is shown in Fig. 7. and the results are presented in Table 2.

The measurement results of the tool-edge radius indicates that it is possible to calculate the radius by using the curves of microscope reading and envelope, which were expressed by the 6th power linear function, and also by knowing effective width.

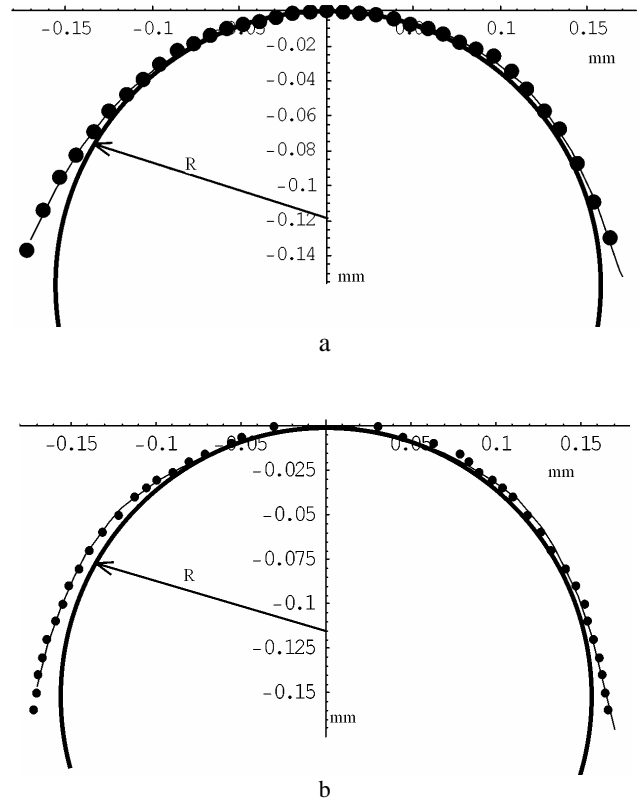


Fig. 7. The calculations of radius for the tool-edge with the radius of 0.150 mm from: a) envelope readings, b) microscope readings

Table 2. Radius of mesured objects

Measured object	Radius, mm (microscope readings)	Radius, mm (envelope readings)
Model - edge $R \approx 2.000$ mm	1.998	2.050
Model - edge $R \approx 1.000$ mm	1.002	1.006
Model - edge $R \approx 0.500$ mm	0.501	0.506
Model - edge $R \approx 0.250$ mm	0.250	0.247
Model - edge $R \approx 0.150$ mm	0.149	0.130
Model - edge $R \approx 0.075$ mm	0.076	0.090
Model - edge $R \approx 0.040$ mm	0.038	0.058

Conclusions

Like in other methods that have been tested by us, the accuracy of the proposed method is significantly influenced by the production precision of the device parts. In the conducted research work the primary objective of measuring the form of the sharp edge non-destructively in an on-line system with satisfactory precision was attained when compared to other methods. Another advantage is that this system is cheap to produce and easy to maneuver with respect to the case when atomic force microscope is used.

The present prototype is designed for the applications requiring to measure edges of arbitrary form. If we have a specific edge form, measurement performance can be improved to a higher level of accuracy.

The disadvantage of this system is related to limitation in measuring and calculating the radius. When some micro-cracks appear or the shape is excessively worn-out, the measurement will be performed only on the tips of the chips.

If it reaches the point where it can correspond to the form of the various edged tools, further improvement of this experimental device results in the increase of precision.

References

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