RESEARCH ON THE DETECTION OF CUTTING TOOL WEAR BY MACHINE VISION

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This paper presents a method of applying a system which consists of an Optoelectronic scanner(TV camera or CCD) and an IBM/pc computer to obtain the micrograph information from the worn region on the flank of the cutting part of the tool and analyze and process the picture by means of imagine processing and mode recognizing technology. The on-line and off-line methods are used respectively to calculate accurately the worn value, recognize the form of wearing and forecast the tool life. At the last, the optimum valued of cutting velocity and feed are given, which meet the principle of the lowest cost and longest tool life. It is proved by experiments that the conclusion of the theoretical analysis and calculation agrees with the practical test. Thearticle provides a practical and precise way of checking and controling cutting tools on line.

Keyword: Machion Vision, Cutting tool, Wear

1. Obtaining the wear imagine on the flank of cutting tool

Cutting tool will be worn after being used. The worn region appears around the corner. There are two kinds of wear: the face wear and the flank wear. In theory and practice, the flank wear is widely used. So, in this research, we collect, process and analyce the flank wear imagine of cutting tool. The system which has been used in the reseach shows in Finl.1.

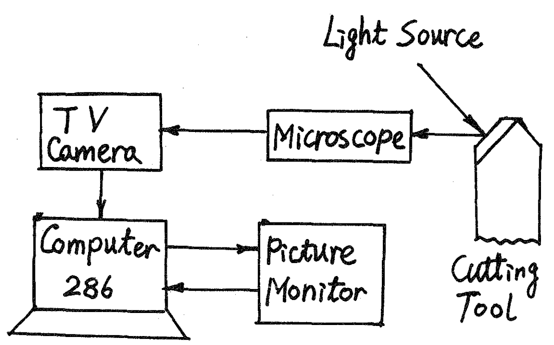


Fig 1.1

The system consists of TV Camera, microscope(30^{x}), Computer and picture monitor. The micrograph has been obtained by the system, which is showed Fig.1of the appendix. In the micrograph, the worn region is closed and irregular. Because of using incandescent lamp for lighting, light affects directly the clarity of the picture and gauging precise. In order to prove gauging precise, the light source must be adjust carefully to make high reflecting light on wear region so the distingush in worn region and unworn region are very clear. the imagine must be reprocessed with smoothing and filtering methods. before being gauged.

2. Preprocessing micrograph and extracting the edge.

2.1 Preprocessing:

Because incandescent is not distriluted equally over the flank of cutting tool. the quality of the pictures are affected and much disturbance takes place in the picture. So the picture must be processed by mediom filter method to cancel the disturbance and make the edge of the wear region clear. After filtering, the gray level histogram can be made to prepare choising the thresholding, which is the key of making binary picture.

2.2 Extracting the edge of wear region

According to the character of geometric state and the value of the wear, the wear type could be recognized. The precision and reliability of recognition relys on the measuring precision for the wear geomety. This research improves mesuring precision by means of making binary image, extracing the edge of worn region on binary picture and gauging the edge.

Selecting threshold is a impartant step of making binary image. When the wear picture is being taken by microscope and TV camera, the flank's wear area is on the centre of the field of microscope. In the picture, there are three parts: worn area, unworn area of the flank and other's parts(back ground). There are deferent gray level in three prats.

Ww0(x, y) is defined to the gray level function of background. ww0(x, y) is distributed equally over the background area (w0).

The unworn part of the flank reflects partly light and shines higher than the background when lighted by incandestent lamp. We definite it's gray level fnuction as Gw1(x, y), which is distributed over the area, Showed as w1.

The worn prat of flank reflect light strongest in the three parts of a picture, It's gray level function is Hw2(x, y), which is distribute over the area showed by w2.

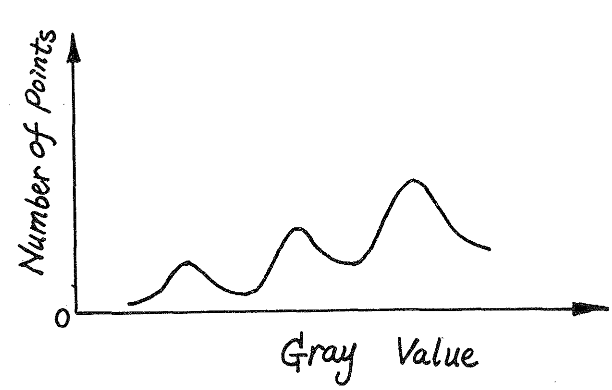
Level function of the image can be described as:

$$f(x,y)=\begin{cases} W(x,y) & x,y\in w0 \\ G(x,y) & x,y\in w1 \\ H(x,y) & x,y\in w2 \end{cases} \qquad (2\text{-}1)$$

Obviously,

$$H(x,y)>G(x,y)>W(x,y) \qquad (2\text{-}2)$$

Therefore, the gray level histogram of the image is showed as Fig.1.2



From these, we can choice the threshold for making binary image. The binary image has been made that shows as the Fig.2 in appendix.

The edge of the worn area can be produced by the methods of scanning, extracting and thinning. The picture processed is shown as the Fig.3 of the appendix.

3.Bulding gauging coordinate system

In the theory and practice, the tool orthogonal plane coordinate system is often used to gaug, design and check the angle of cutting tool according to the Internation Oarganization for Standardizalion. Because this research only uses two dimensional coordinate for measurement we build the gauging coordinate system as follows Fig3.1

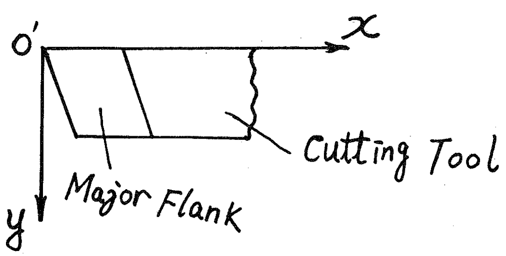


Fig 3.1

In the coordinate, the coordinate point is on the tool corner, the axis of abscissa is parallel to tool reference plane, and the axis of ardinate is vertvcal to tool reference plane. These axes are called relative axes. While the axes, which are definited by imagion system, are called absolute axes, In absolute system, the axis oj refers to vertical direction and axis oi refers to line scanning direction in the computerimage system, These two coordinace systems shoued be posited correctly follows as Fig.3.2

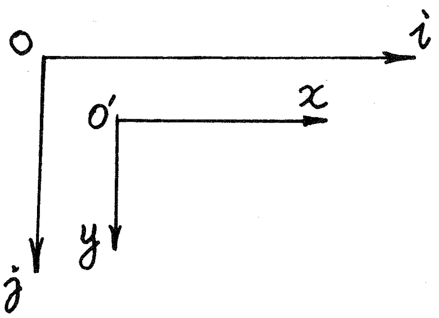


Fig 3.2

But, the xoy system often takes correct pasition to ioj system showed as Fig3.3 when taking micrograph. In this way, gauging erroes have been produced.

It is nessary to adjust the relative position between ioj and xo'y. The o'xy system must be build at the practical position of cutting tool in taking picture, and then rotated or moved until the axes o'xy take correct position to oij system. Taking lath cutter with 0° tool cutting edge inclination as an example. The processing of building and transforming relative coordinate system is given as follows.

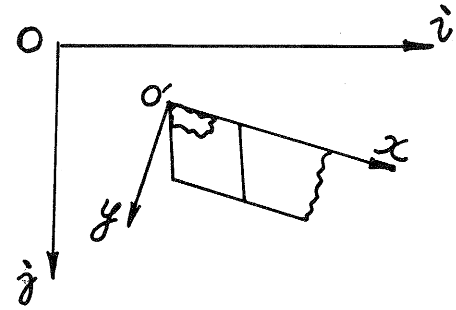


Fig 3.3

Fig3.3 shows the position of cutting centre in microscope visual field. To constructe o'xy coordinate, the lines, l_1 and l_2, which are the projctions of the face and the major flank of cutting tool in o'xy plane, should be produced, then the intersection point of l_1 and l_2 could be determind. This point could be refered to as cutting corner after wearing.

After cutting procession, the parts of the face and the major flank around the corner have been worn partly. So the projectors of the two planes in o'xy are irregular curve. We take regression method to gain l_1 and l_2.

Cutting corner o' appears a little curve in micrograph. Basing on caculating every slope of the point on curve, the point which has the largest slope could be selected. Then, the whole picture of the wear being taken by camera is rotated around the picture's weight centre until the point with largest slope is placed on the highest position of the picture. From the highest point to the lowest point of the curve, we can make regression respectively in the two direction along the right and left of the highest point.

It be supposed that the points which take part in regression are on the edge of the worn area. We can take several x with unequal values($x_1, x_2, \cdots, x_n$) to test independently, then we could gain a series of the samples: $(x_1, y_1), (x_2, y_2), \cdots, (x_n, y_n)$. IF there are $y \sim N(a+bx, \sigma^2)$ for every x, or $y=a+bx_i+\varepsilon_i$, $\varepsilon_i \sim N(o, \sigma^2)$, $i=1, 2, \cdots, n$ for every point(x_i, y_i), the probability density function is:

$$\frac{1}{\sigma\sqrt{2\pi}}\exp[-\frac{1}{2\sigma^2}(y_i-a-bx_i)^2]$$

Because $y_1, y_2, \cdots$, and y_n are independent for each other their coalition's probability density is:

$$L=\prod_{i=1}^{n}\frac{1}{\sigma\sqrt{2\pi}}\exp[-\frac{1}{2\sigma^2}(y_i-a-bx_i)^2]$$

$$=(\frac{1}{\sigma\sqrt{2\pi}})^n\exp[-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(y_i-a-bx_i)^2] \quad (3\text{-}1)$$

In above formula, a and b can be estimated by proble method. Obviously, when L has the largest value the function $Q(a,b)=\sum_{i=1}^{n}(y_i-a-bx_i)^2$ has the least value.

The following coupled equations can be obtained by deriving Q to a and b respectively:

$$\frac{\partial Q}{\partial a}=-2\sum_{i=1}^{n}(y_i-a-bx_i)=0 \quad (3\text{-}2)$$

$$\frac{\partial Q}{\partial b} = -2 \sum_{i=1}^{n} (yi-a-bxi)xi = 0 \quad (3\text{-}3)$$

Then we can gain following equations by soving above equations:

$$\begin{cases} na+n\bar{x}b = n\bar{y} & (3\text{-}4) \\ n\bar{x}a + \sum_{i=1}^{n} xi^2 b = \sum_{i=1}^{n} xiyi & (3\text{-}5) \end{cases}$$

In these equations, x is the mean of the xi, y is the mean of the yi. Because the xi are not equal to zerro at the same time, the coefficient determinant is:

$$\begin{vmatrix} n & n\bar{x} \\ n\bar{x} & \sum_{i=1}^{n} xi^2 \end{vmatrix} = n \sum_{i=1}^{n} xi^2 - n^2 \bar{x}^2 \quad (3\text{-}6)$$

Obviously, the coefficient determinant is not equal to zerro, so there is only result. The proble value of a and b are:

$$\hat{a} = \bar{y} + \hat{b}\bar{x} \quad (3\text{-}7)$$

$$\hat{b} = \frac{\sum_{i=1}^{n}(xiyi - n\bar{x}\bar{y})}{\sum_{i=1}^{n} xi^2 - n\bar{x}^2} = \frac{\sum_{i=1}^{n}(xi-\bar{x})(yi-\bar{y})}{\sum_{i=1}^{n}(xi-\bar{x})^2} \quad (3\text{-}8)$$

So, the line vegression formula could be obtained as follows:

$$\hat{y} = \hat{a} + \hat{b}x \quad (3\text{-}9)$$

Therefore, we can get two line equations exprersing l1 and l2 through regressing respectively from the left and right direction of the highest point of the cutting corner. These lines represent approximatively the projects of the face and major flank of cutting tool before wearing. Basing on the formulae of l1 and l2, the intersection point of l1 and l2 can be obtained. Then, rotating the pcture of worn area around the point until l1 being horizontal that is paralled with oi and regarding l1 as o'x ax'is and the intersection point as corner, the gauging coordinate system(o'xy) could be built as showed as Fig4 in appedix.

4. Detecting, classifying and recogniging the wear state

The worn state of the major flank is often classified two types: one is refersed to as the ordinary wear[3] which includes cracking without sharp deformation, equal wear and corner wear, another type is refersed to as inordinary wear which includs centrical wear and verge wear. The recognazing models which descrrbe these types of wear have been built based on the geometric state of wear. x1 and y1 are choiced as characteristic constants of describing the wear geometric character. x1 and y1 are separately defined as:

$$x_1 = \frac{xp}{xmax} \quad (4\text{-}1)$$

$$y_1 = \frac{ymax}{yave} \quad (4\text{-}2)$$

In the formulae, xp is the coordinate of the largest wearing point in the worn area, xmax is the largest coordinate of x's derection, yave is the mean of wear value(y), ymax is the largest wearing point of the worn area. They are showed in Fig4.1

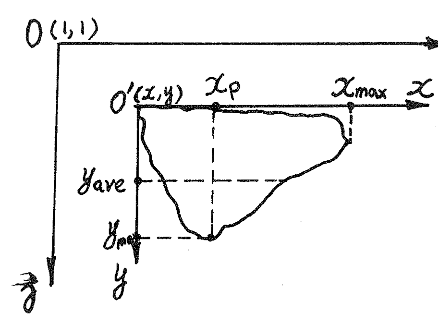


Fig 4.1

xmax, ymax and xp could be obtained by detecting the worn area with line scanning then yave can be taken out. So the wear model can be recognized according to the model schedule made before.

In addition to recognazing wear state, the worn value would be gauging, in this studing. Worn value, VB', is defined as:

$$VB' = \frac{ymax}{k} \quad (4\text{-}3)$$

k is the amplification of the optical system.

Comparing practical VB' to theoritical VB, the wear degree of the cutting tool could be determined, then we can ascertain wither the cutting tool should be changed.

5. Forecasting the tool life and optimizing cutting process

There are two major ways to forecast tool life: on line and off line method. The on line method is the way which could forecast the tool life effectively by using gauging tool such as microscop for detecting wear value and state in deferent time of cutting process. While the off line way uses theoretical or testing formula for counting wear value and forecasting tool life based on cutting data base. In this reseach, on line method has been tanken to checking wear value, forecasting tool life and building cutting data bace. Then, off line method has been taken to optimizing the cutting process.

5.1 On line method

According to Taylor formula:

$$VB = At^{b1} f^{b2} v^{b3} \quad (5\text{-}1)$$

VB is wear value, t is cutting time, f is cutting feed, v is cutting velocity, A, b1, b2, b3 are constants. It could be abtained by taking lagarithm:

$$\ln VB = b1 \ln t + b2 \ln f + b3 \ln v + \ln A \quad (5\text{-}2)$$

Obviously, this equation indicates a line in loganithmic paper. If the two points on this line are known, the equation can be defined. So the VB at any time can be determined. On the contrany, the tool-change time(tmax) could be taken out based on the limit of wearing, VBmax.

Through taking t1, t2 and VB1, VB2, to the two point equation of line, the followed formula can be gained

$$\frac{\ln VB - \ln VB1}{\ln VB2 - \ln VB1} = \frac{\ln t - \ln t1}{\ln t2 - \ln t1}$$

$$\text{or: } t = t1\left(\frac{VB}{VB1}\right)^{\ln\left(\frac{t2}{t1}\right) / \ln\left(\frac{VB2}{VB1}\right)} \quad (5\text{-}2)$$

In the equation, If VB equal VBmax, the tool life t could be taken.

In cutting process, there are mamy facts to affect the wear state of cutting tool, including regular facts and random facts. Therefore, the testing wear curves at the same condition are deferent. There are ignorance erroes when we determin the relation of VB and t. To get higher precision, many sample points such as (t1,VB1),(t2,VB2)),…, (tn,VBn) have been used to determine the relation of wear (VB) and tool life(t) by regressing in the test. So, the followed regression equation could be taken:

$$\ln VB = a + b\ln t \quad (5\text{-}3)$$

in above equation: $a = \overline{\ln VB} - b\overline{\ln t}$ (5-4)

$$b = \frac{\sum_{i=1}^{N} \ln Ti \ln VBi - n\overline{\ln t}\cdot\overline{\ln VB}}{\sum_{i=1}^{N} (\ln Ti)^2 - n(\overline{\ln T})^2}$$

$$\left(\overline{\ln VB} = \sum_{i=1}^{N}\frac{\ln VBi}{N} \qquad \overline{\ln T} = \sum_{i=1}^{N}\frac{\ln Ti}{N}\right)$$

On the supposition that VB equals VBmax, the t related to VBmax is:

$$\ln t = \frac{\ln VBmax - a}{b}$$

$$\text{or: } t = \exp\left(\frac{\ln VBmax - a}{b}\right) \quad (5\text{-}6)$$

5.2 off line method

5.2.1 The way of using general Tayler equation.

The equation is:

$$VB = Aap^{b1} f^{b2} v^{b3} \quad (5\text{-}7)$$

(ap is the back engagement)

The equation can be changed as by taking logarithm:

$$\ln VB = \ln A + b1\ln ap + b2\ln f + b3\ln V \quad (5\text{-}8)$$

In cutting process, a series of equation as followed could be received by taking a number of four datas about ap、f and v into the equations. There are:

$$\begin{cases} \ln VB1 = \ln A + b1\ln ap1 + b2\ln f1 + b3\ln V1 \\ \ln VB2 = \ln A + b1\ln ap1 + b2\ln f2 + b3\ln V1 \\ \ln VB3 = \ln A + b1\ln ap1 + b2\ln f2 + b3\ln V2 \\ \ln VB4 = \ln A + b1\ln ap2 + b2\ln f2 + b3\ln V3 \end{cases}$$

From these we can obstain:

$$b1 = \frac{(\ln VB4 - \ln VB3) - b3(\ln V3 - \ln V2)}{\ln V3 - \ln V2}$$

$$b2 = \frac{\ln VB2 - \ln VB1}{\ln f2 - \ln f1}$$

$$b3 = \frac{\ln VB3 - \ln VB2}{\ln V2 - \ln V1}$$

$$A = \exp[\ln VB1 - (b1\ln ap1 + b2\ln f2 + b3\ln V1)]$$

After determining A, b1, b2, b3, the wear value VB corresponding to machine time t could be taken by using general Taylor formula.

5.2.2 The way of using depierevx formula

In theory of metal cutting process, Depierevex formula is:

$$t = \exp\left[\frac{a_{Kv}}{a_m} V^{am} \frac{a_{if}}{a_n} + ac\right] \quad (5\text{-}13)$$

$$t = e$$

a_{Kv}, a_m, a_{if}, a_n and ac are constants. In order to determin these constants, It must be done to taking five groups of date: (t1, V1, f1), (t2, V1, f2) , (t3, V1, f3), (t4, V2, f3),(t5, V3, f3), through the testing. Then, these data are taken into the logarithmic state of Depierevx formula:

$$\ln t = \frac{akv}{am} V^{am} \frac{aif}{an} f^{an} + a_c \quad (5-14)$$

So, We can obstain a series of equation:

$$\begin{cases} \ln t_1 = -\frac{a_{Kv}}{a_m} V_1^{a_m} - \frac{a_{if}}{a_n} f_1^{a_n} + a_c \\ \ln t_2 = -\frac{a_{Kv}}{a_m} V_1^{a_m} - \frac{a_{if}}{a_n} f_2^{a_n} + a_c \\ \ln t_3 = -\frac{a_{Kv}}{a_m} V_1^{a_m} - \frac{a_{if}}{a_n} f_3^{a_n} + a_c \\ \ln t_4 = -\frac{a_{Kv}}{a_m} V_2^{a_m} - \frac{a_{if}}{a_n} f_3^{a_n} + a_c \\ \ln t_5 = -\frac{a_{Kv}}{a_m} V_3^{a_m} - \frac{a_{if}}{a_n} f_3^{a_n} + a_c \end{cases}$$

From these equations, we can gain:

$$CB^{an} = A^{an} - 1 + C \quad (5\text{-}15)$$

In the formula: $C = \frac{\ln t2 - \ln t1}{\ln t3 - \ln t2}$, $B = \frac{f3}{f1}$, $A = \frac{f2}{f1}$ the constant a_n could be taken out througt solving (5-15) by numerical method.

In the same way, the folluwed conelcision can be taken from above equations:

$$\frac{1 - G^{am}}{1 - D^{am}} = E \quad (5\text{-}16)$$

In the formula: $G = \frac{V2}{V1}$, $D = \frac{V3}{V1}$, $E = \frac{\ln t4 - t3}{\ln t5 - \ln t3}$, from (5-16), the a_m can be taken out and then the a_{if}, a_{Kv} and a_c could be determined:

$$a_{if} = \frac{a_n(\ln t2 - \ln t1)}{f1^{an} - f2^{an}}$$

$$a_{Kv} = \frac{a_m(\ln t4 - \ln t3)}{V1^{am} - V2^{am}}$$

$$ac = \ln t1 + \frac{akv}{am} V1^{am} + \frac{aif}{an} f1^{an}$$

So far, Depierevex formula is defined and the tool life, t, can be caculated and forecasted.

Mostly, the goal of optimizing cutting process is for spares to get required quatity and shape in the lowest cost. Combining the Depierevex formula with the cost formula, we can gain the best cutting velocity (V0), best feed (f0) and best tool life (t0), and then we can get the lowest cost k0.

6. Gauging precision

For the whole system, the errors come from two respects. One is produced in process of detecting and changing image signal and another is produced when image signal be processed.

This study only analyses the erro coming from signal collecting and changing process beniefly, More research on the erro will be given in future. Camera len's distortion erro is one of major erros[2] [4]. In these erroes, the radio distortion erro is very important. This erro has the lest value in the centre field of picture, which reaches 0.2-0.3 image point in sixty percent area of the field, and it has about one image element around the edge of field. Other distortion are so small that can be ignored. In our research, the flank wear area is posited in the centre of the field, so the distortior erro is about 0.0015 um in the direction of x axis and about 0.0011 um in the direction of y axis auording to the amplifging time of the system.

Except optical distortion, there are erroes from A/D and D/A board, the research made by the schol'ar of our university shows that these erroes can cause position changing of image element and the gradation changing of image element. This erro's value is about one image element.

According to the theory of combining erroes, the erro of the system is about 0.5um, It is witnessed that the relative erro of forcasting tool life is 1.2 percent by testing.

7. Conclusion

As the experiment shows, it is a high precise and practical method to use Machion Vision for detecting and controling the wear of cutting tool. This method is difficalt to detect the wear on time. because limited by the cutting conditions such as using cool liquid ect. But, the development of the method called neural system pave the way for using Machion Vision to detect cutting tool wear on line and on time.

8. References:

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9. Appendix

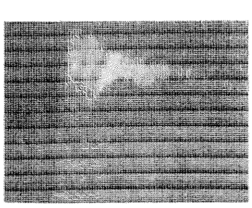

Fig. 1

Fig. 2

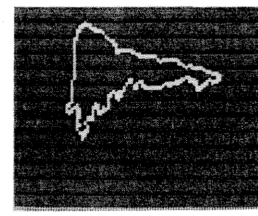

Fig. 3

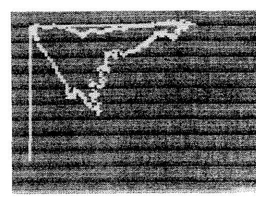

Fig. 4