AUTOMATIC DEFECT RECOGNITION IN CUTTING TOOLS

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ABSTRACT

Automated metal-cutting manufacturing facilities are strongly dependent on the availability, on demand, of properly configured cutting tools. Tools must not only have the correct geometry but must also be in a suitable state for producing workpieces to the required standards of dimensional accuracy and surface finish. In earlier, manually-operated systems, this was readily achieved through operator skill and vigilance but, in automatic systems, other means must be employed. To this end, work has been undertaken at the University of Hull to develop automatic tool inspection systems based on the use of lasers to scan the cutting edges of tools for the presence of defects. Physical defects such as progressive wear or chipping of an edge can be detected and characterised by such means. Such systems can be implemented in several ways but the most useful are those which allow inspection of tools whilst held either in a local storage system, accessed by an automatic tool changer (ATC), or in the machine tool itself. The paper describes both arrangements and refers specifically to recent work concerned with data capture and signal processing techniques necessary to implement fully automatic inspection systems.

INTRODUCTION

The need for a constant supply of cutting tools in good condition has long been a necessity for manufacturing industry. Moreover, in recent years, with the move toward automated flexible manufacturing systems, this need has become more specific in the sense of automated supply of such tools.

On-line systems for monitoring tool condition have been available for a number of years, but they have practical limitations. In addition, in an industrial environment, many such systems fail to function accurately and reliably. Another drawback is that they are inferential techniques, monitoring a diverse range of signals, such as acoustic emission (AE), power, torque and spindle current. However, the effect of changes in tool wear are minimal compared to changes in machining parameters, such as spindle speed, and feedrate (1).

An alternative, potentially more reliable technique, is tool inspection by laser scanning. This is an electro-optical technique utilising a direct sensing method carried out intermittently, as opposed to an indirect technique operating continuously. This method has previously been applied successfully to orientation applications (2), particularly in the automotive industry (3), and more recently to the quality inspection of indexable cutting tool inserts during manufacture (4).

This paper focuses on recent work carried out at the University of Hull on the automatic in-service inspection of milling cutters, as well as the potential application of the system to monitor similar cutters whilst held in the main spindle of a Vertical CNC Milling Machine.

The research has also yielded some interesting results arising from the application of sophisticated signal processing of the captured data. Programs have been written in-house in order to evaluate this data automatically and return information concerning the type, extent and exact location of wear and defect characteristics. The outcome is to return statements to a machine operator or machine control unit as to the action that needs to be taken on any tool to allow it to continue operation. Additionally, if tools are rendered defective, they can be held in an ATC, until such time as a machine operator becomes available to dispose of it.

LASER SCANNING TECHNIQUE

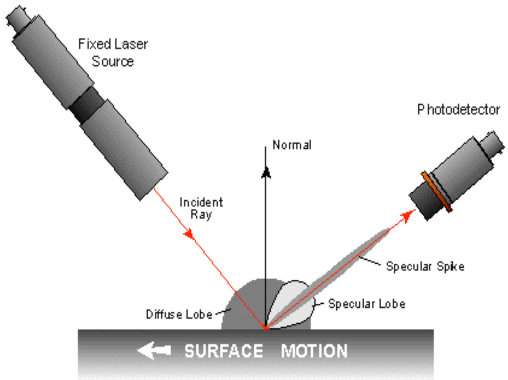

Figure 1 : Theory of laser scattering.

The cutting edge of a tool can be opto-electronically inspected for wear and defects. Due to the surface being rough or worn, scattering of the light occurs from the surface, either specularly or diffusely. A light source suitable for tool condition monitoring (TCM) must be well defined, with consistent beam characteristics. Laser light is the best source as it is coherent, monochromatic, highly collimated and highly directional. A low power, Class 2 laser diode module (1mW) can be used for the purpose of inspecting a cutting tool, as it meets these requirements, Figure 1.
Light reflecting from a metallic surface can be analysed using either Physical Optics (5) or Geometrical Optics, the former being a complex electromagnetic model for investigating specular spikes and lobes and is unsuitable for analysis of scattered light from cutting edges. Geometrical modelling (also known as Ray theory) is better suited to analysing macroscopic defects such as cutting edge wear (6).

INTEGRATED TOOL INSPECTION SYSTEM

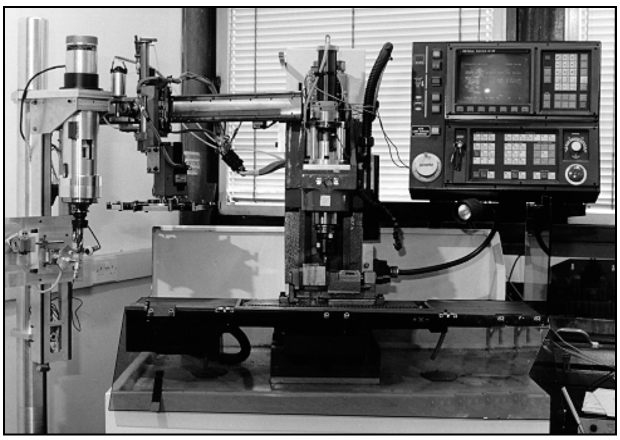

Figure 2 : Integrated laser-based inspection system.

Laser scanning provides a good basis for cutting tool inspection systems that are based in a toolroom or, more usefully, integrated with a CNC machine tool. Figures 2 and 3 show a demonstration system designed to operate in conjunction with the automatic tool changer of a small CNC machining centre. The tool changer has been modified to allow tools to be transferred, in their tapered holders, into an inspection station. The four-axis laser/detector system is driven by computer-controlled stepper motors along the cutting edges of the tool according to a pre-defined program or 'move template'.

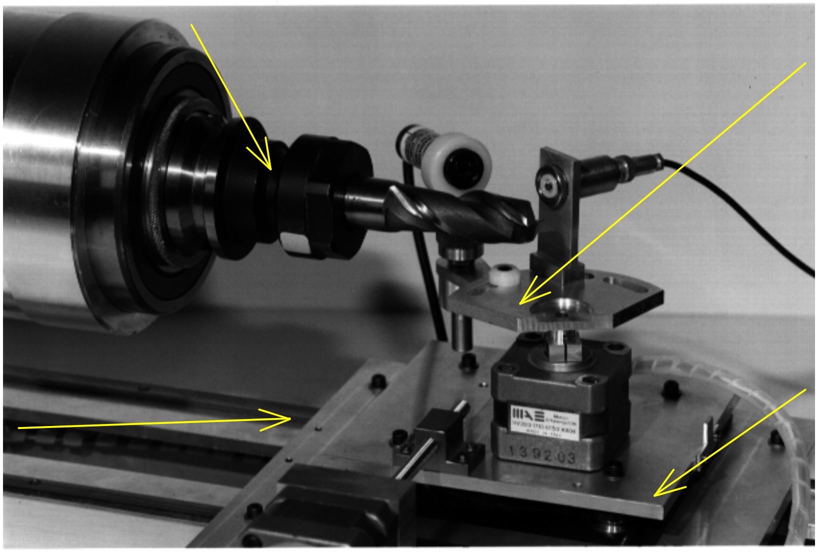

Figure 3 : Close up of the scanning head.

INSPECTION OF SPINDLE MOUNTED CUTTING TOOLS

Previous work upon laser inspection has been based on the use of a secondary spindle, which allows the system to operate off-line, with a tool change arm to enable it to be integrated with a CNC machining centre.

Recent developments have involved inspecting tools held in the main spindle of a Kryle CNC machining centre (Figure 4) and this arrangement provides for intermittent on-line inspection. In practice, machining is halted to enable the inspection of the tool to take place, after which the machining cycle can be restarted. This arrangement is far more versatile in that it can be fitted to existing machines more readily and is less complex. On the other hand, off-line inspection does not interrupt production.

Figure 4 : Vertical CNC milling machine.

The underlying principle of tool inspection is the same in each implementation and involves the control of the scanning cycle and the laser optical elements themselves.

OPTICAL ELEMENTS

The primary components are the laser and detector which, in the prototype system, are mounted directly on the bed of the milling machine. The inspection platform uses a single laser diode module, as described earlier, which is focused at the cutting edge of the tool, with a photo-detector mounted in front of the laser to capture the reflected light. The incident angle of the laser is critical, to ensure the reflective light is collected by the photodiode, Figure 5(b). The amount of light which falls on the photodiode varies with the physical condition of the cutting edge of the tool. When the reflective light has reached the photodiode it is converted to a voltage signal. The voltage level is typically very low (ca. 0.2V) and needs to be amplified and filtered. Finally, the signal is converted from analogue into digital to facilitate its subsequent processing.

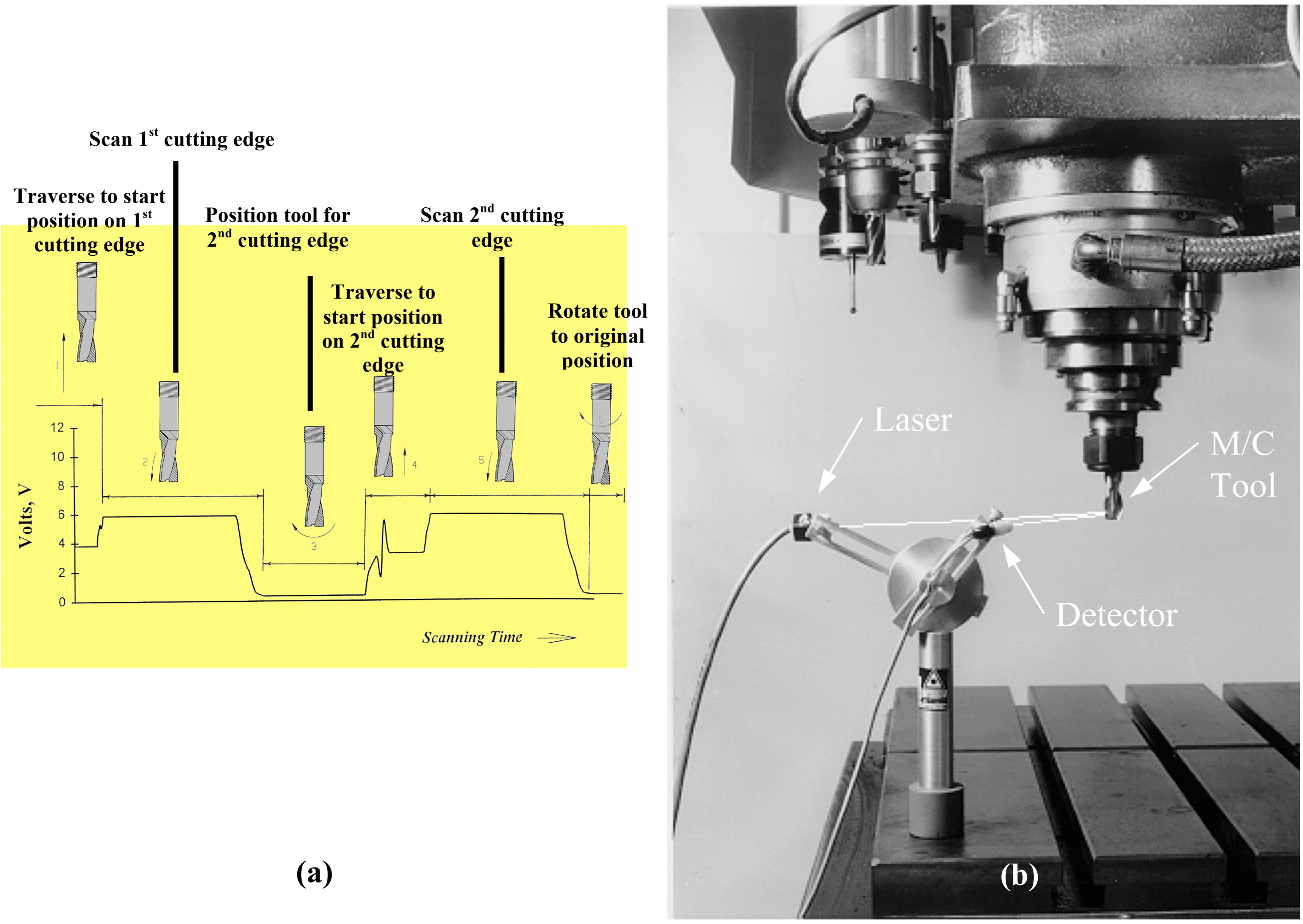

Figure 5 : (a) Move template characteristics and (b) Side view of the laser and detector in relation to the tool.

CONTROL

The overall control of the scanning cycle is achieved by a PC, which controls both the downloading of the part program and the data for the stepper motors. In the off-line four axis inspection system, the tool was slowly rotated (ca. 5 rev/min) in a separate spindle, driven directly by a stepper motor. When the tool is to be inspected whilst held in the main spindle of a machining centre, the same slow rotational speed is required. However, the minimum smooth spindle speed which could be achieved on the Kryle was 50 rev/min. To overcome this problem, an auxiliary stepper motor was mounted adjacent to the main spindle column to provide a friction drive on the rear of the spindle belt drive. Control of the other axes was not as critical and standard machine feed rates could be utilised. To maximise the machining envelope, the tool inspection unit was mounted at the edge of the machine table. Prior to carrying out a scan of a tool, the machine table has to be moved to a datum position to centralise the inspection unit relative to the main spindle. A tool could be then be collected from the carousel ready for scanning and, once installed in the main spindle, lowered into the inspection zone where it breaks the laser beam.
To enable the laser and detector to scan a specific tool profile, a combination of an NC part program and stepper motor drive data is required, to create a move template. The NC program is sent from the PC down an open channel DNC link (RS232), which provides immediate actuation of the machine axes. At the same time, drive data is sent directly to the stepper motor, controlling rotation of the main spindle and both actions are synchronised via a master program.

Operation No.	*Motion Type*	*Operation*

1	**Linear**	**Traverse the tool and the spindle down to the datum point adjacent to the laser and detector**
2	**Helical**	**Scan 1st cutting edge (downwards)**
3	**Rotational**	**Position tool for 2nd cutting edge**
4	**Linear**	**Traverse laser/detector to start of 2nd cutting edge**
5	**Helical**	**Scan 2nd cutting edge (downward)**
6	**Rotational**	**Return tool to original position**

Table 1 : Trace format correlation to the move template.

Once the laser is aligned to the first flute of the tool, a scanning cycle is initiated. This incorporates the two sets of control data (motor driver data and NC code) to provide for scanning features such as the helical cutting edges. Figure 5(a) shows the elements of the scan cycle with movement details in Table 1. Once the scan cycle has been completed, the tool is either allowed to commence cutting or is returned to the carousel by the tool changer, depending on its condition.

SIGNAL PROCESSING

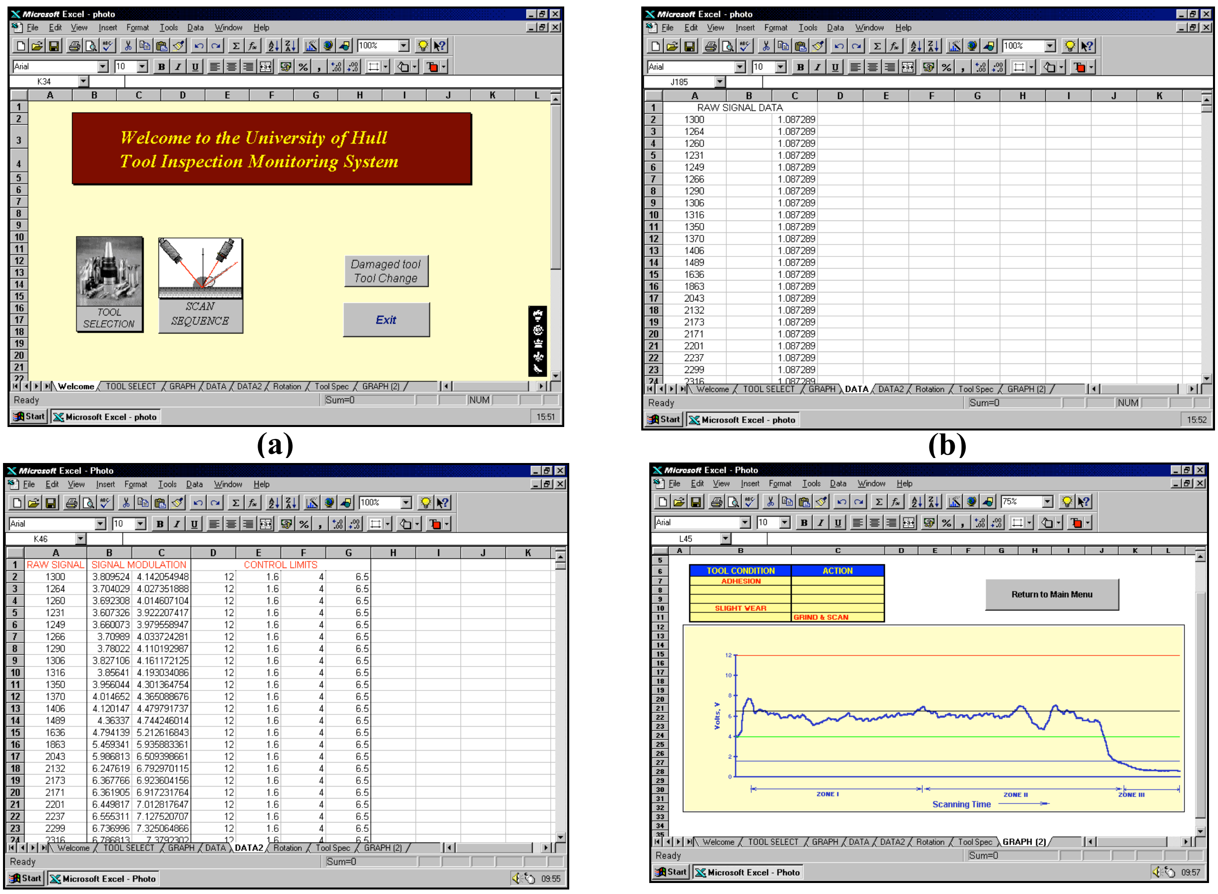

Figure 6 : Screenshots of the signal processing macro.

The digitised data from the scanning sequence can be analysed using a standard spreadsheet package (Microsoft Excel 5.0). The information enters the system as a linear sequence of data, representing the reflected signal magnitude in a range 0-4095, as shown in Column A, Figure 6(b). This data is directly proportional to the signal magnitude in volts (0-12V). Figure 6(a-d) illustrates the key stages in the execution of this macro program. The entire operation can be carried out centrally from the computer. The machine operator can select tool geometry, size, tool type and engage the inspection apparatus and tool change operations, Figure 6(a).

A macro program was written in Visual Basic, which can operate on this data to plot the information as a chart as well as evaluate the wear characteristics on the cutting edge in the critical wear zone (zone II). The data can thus be extrapolated to include critical threshold values for wear and damage characterisation. These control limits are shown in Columns D to G, representing signal saturation [D], interface between cutting edge and clearance face for a monolithic tool [E], interface between slight wear and significant wear [F] and error accounting for signal noise [G], Figure 6(c).

This information can be used to drive algorithms designed to display tool condition characteristics based on the number of instances of these limits being exceeded. In the example shown in Figure 6, if the limits are exceeded on more than 50 occasions, display of an appropriate tool condition is triggered. Any condition, or combination of conditions, enables an appropriate action statement. In the example, a combination of adhesion (workpiece material adhesion to the tool) and slight wear (wear on the cutting edge with flank wear magnitude less than 300(m) is indicated. This requires that the tool be ground on its clearance face and monitored more frequently to track the transition from slight to significant wear. This outcome is verified by the signal response in zone II, Figure 6(d) and can also be verified visually from Figure 7.

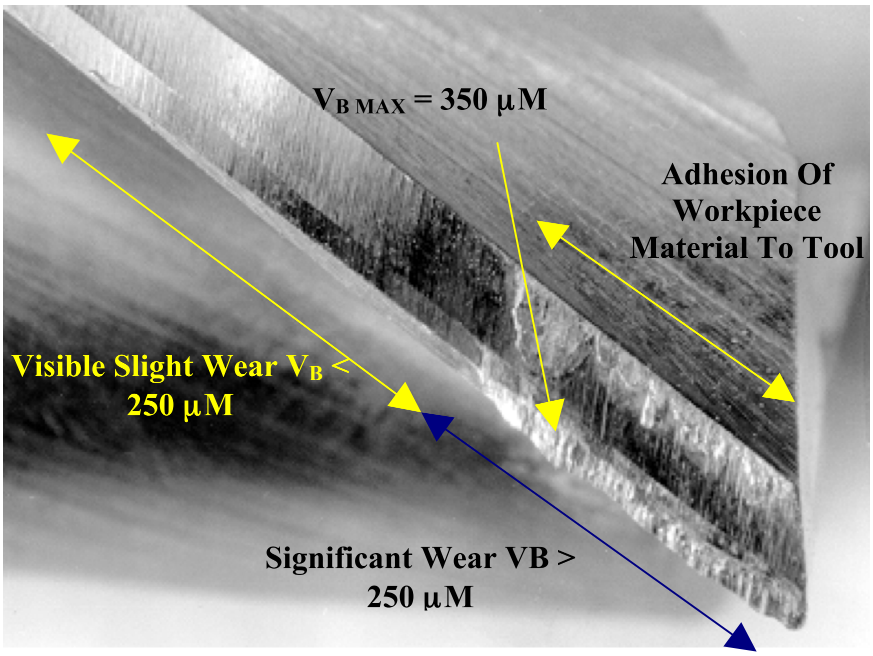

Figure 7 : Visual verification of cutting tool condition.

CONCLUSIONS

The work described in this paper demonstrates an important step forward in the application of laser-scanning as a method for monitoring the condition of cutting tools. It has been demonstrated that a scanning system can be successfully integrated with a machining centre such that tools held in the main spindle can be scanned via the operation of the machine tool axes and control of spindle rotation. This obviates the need for a separate inspection station as used in earlier implementations of the system. It has also been shown that the physical condition of the cutting edges of tools can be deduced from the output of the laser scanning system and used to trigger the display of information to an operator or, in unattended machining systems, to communicate directly with the machine control unit. By these means, defective tools can be inhibited and consequential damage to workpieces avoided.

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