Advances in Tool Management Systems

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1. INTRODUCTION

Despite impressive advances in forming and joining technology, manufacturing industry is still heavily reliant on conventional material removal processes, in which controlled shearing of the work-piece occurs. Such processes typically involve the use of CNC machining centers, which, in principle, are capable of sustained periods of unattended operation. However, the quality of the finished work-piece, in terms of its conformance to dimensional and surface finish requirements, is strongly dependent upon the cutting conditions and, crucially, upon the state of the cutting tools used. A number of cutting tool life management systems are employed but these are usually based on expired life criteria and are of limited applicability. More sophisticated procedures exist, typically based on acoustic emission or spindle torque sensors, for dynamically sensing tool condition during operation. Such systems are potentially more useful but still only indicate that some aspect of the cutting process has changed and usually require human intervention.

The current work, carried out in conjunction with the University of Hull, UK, addresses the need for better control of machining processes with the objective of increased operating efficiency based on reduced scrap, rework and lower tool inventory. The work reported here is primarily concerned with the application of intelligent systems to tool management and is based on the use of laser scattering techniques to detect and characterize edge defects in milling cutters [1].

Such processes involve the use of cutting tools which are significantly harder than the work-piece itself and are usually carried out on CNC machining centers, either as stand alone devices or as integral parts of machining cells and systems. Such systems typically include automated tool and work-piece transport/handling and swarf management and, in principle, are capable of sustained periods of unattended operation in a 'lights out' factory environment.

Investment in cutting tools is not trivial and in a study of a large UK manufacturing company, with a tool inventory value of almost £3 million (AED 17.1M), it became apparent that some tools could be used in a less than optimum condition whilst others were needlessly replaced or refurbished.

The cutting process itself can be overseen by some form of adaptive control and several systems of differing complexity are commercially available. Most systems are relatively unsophisticated in that they control a single machining parameter, usually feed rate, in order to keep spindle torque within predefined constraints. These systems in no way compare with the sensitive control capable of being exercised by a skilled machinist. Furthermore, they are unable to dynamically react to observable changes in the condition of the work-piece as a result of the cutting process.

2. LASER SCANNING TECHNIQUES

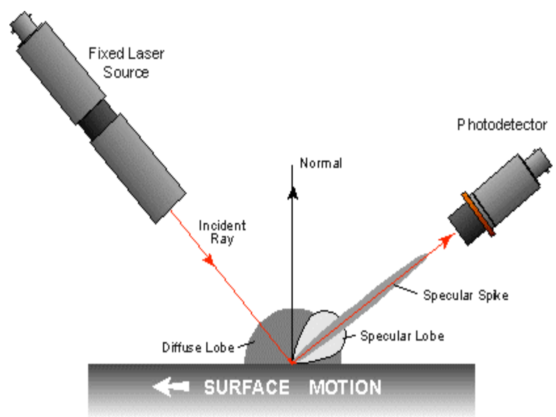


Fig. 1 : Theory of laser scattering.

The principle of laser scanning (Fig. 1) is relatively simple and relies on the fact that physical features of a solid surface will reflect incident light in a way that is directly attributable to their geometry [2]. Low power (<1mW) lasers are used because they provide a consistent and coherent incident light source [3]. Suitable detectors, usually in the form of photo-diodes, are arranged to capture the reflected light patterns, which are subsequently stored and processed to extract data related to the scanned surface. By this means, intended features or defects on a surface can be recognized and assessed. The principle of operation is well established and widely applicable and has been used by researchers at Hull as a basis for the automatic detection of defects in cutting tools [4].

Milling tools have relatively complex geometry and often incorporate helical cutting edges, which have to be tracked by the laser scanner and detector. Fig. 2 shows an early prototype device for the semi-automatic inspection of end milling cutters. Computer-controlled stepper motors were used to translate and rotate the cutter under an inspection head comprising a single fixed laser and detector. A CNC 'move template', specific to a particular tool, was written to obtain the necessary combinations of rotation and translation to track the cutting edges. Such a device would be suitable for use in a central tool store to monitor edge condition before the tools were allocated to machining areas. However, a more useful implementation of the device is achieved when it is integrated with the local tool storage system of a machining centre. Fig. 3 shows an example of such an arrangement on a small CNC milling machine in the laboratory at Hull. Tools can be automatically transferred from the tool magazine to the inspection station whilst cutting proceeds with another tool. All tools are scanned prior to the commencement of the machining operation and then subsequently after each tool has been used for cutting. After inspection, the tool condition is written to the tool data file in the machine control unit (MCU) and, if significant defects are detected, a back-up tool can be used when next required.

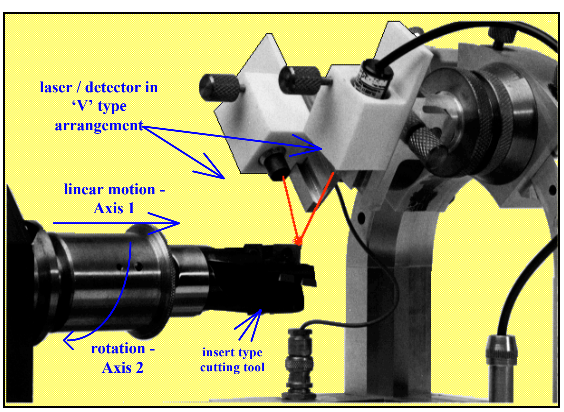


Fig. 2 : Prototype device for inspection of milling cutters.

3. IN-SERVICE INSPECTION OF CUTTING TOOLS

Laser scanning provides a good basis for cutting tool inspection systems in a tool-room or, more usefully, integrated with CNC machine tools themselves. A demonstration system was thus developed to operate in conjunction with the automatic tool-changer (ATC) of a small CNC machining centre. Modifications had to be made to the ATC to allow tools, in their tapered holders, to be transferred into a separate, adjacent, inspection station. The 4-axis laser/detector system was driven by computer-controlled stepper motors along the cutting edges of a tool according to a pre-defined 'move template' [5].

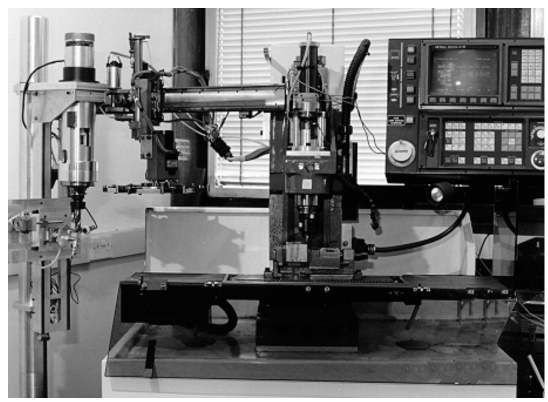


Fig. 3 : Integration of laser-based tool inspection system with CNC machining centre.

Tool wear patterns and defect characteristics were identified by comparison with a master trace and their severity assessed in terms of the likelihood of consequential work-piece damage. The tool database in the memory of the Machine Control Unit (MCU) could be updated to register tools unsuitable for further use. Selection of such tools would be inhibited and 'sister' tools selected, subject to availability. The principles demonstrated can be readily applied to full-size machining centers with local access to several hundred individual tools. The scanning time is typically 1–2 minutes but tools can be scanned in a variable sequence to ensure that they have been inspected well in advance of their requirement for a machining operation.

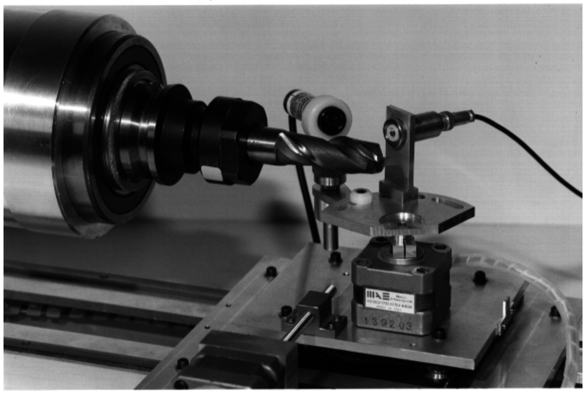


Fig. 4 : Close-up of laser/detector assembly.

Sophisticated tool management can be achieved by the use of appropriate signal-processing techniques. The digitized signal from the tool scanning sequence can be conveniently analyzed using the Visual Basic programming language. Information on tool condition is captured as a linear data sequence, representing the reflected signal magnitude, in the range 0–12 Volts. The Visual Basic program is primarily designed to assess the condition of the tool edge in the critical wear zone (Zone II in Fig. 5). This is achieved by reference to control limits representing signal saturation, the physical boundary between the cutting edge and clearance face, the transition from mild wear to severe wear and variations due to signal noise [6].

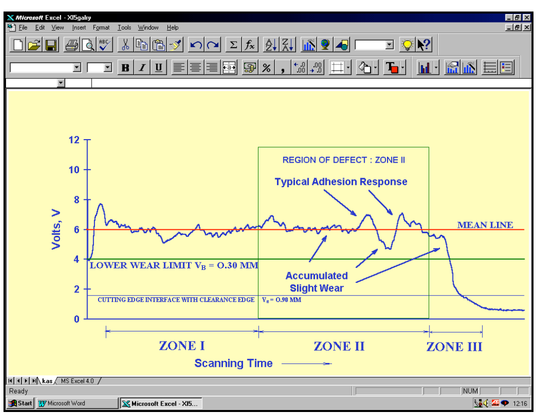


Fig. 5 : Screenshot of the signal processing macro for a worn tool.

The information contained in the captured traces can be used to drive algorithms to display tool condition categories based on the number of instances a particular control limit is exceeded. Any highlighted condition triggers a warning display. In the example shown in Fig. 6, a combination of work-piece adhesion and mild flank wear (<300um) is indicated. The recommended action is that the tool be ground to improve the cutting edge condition and then monitored at more frequent intervals to monitor any transition from mild to severe wear (Fig. 7).

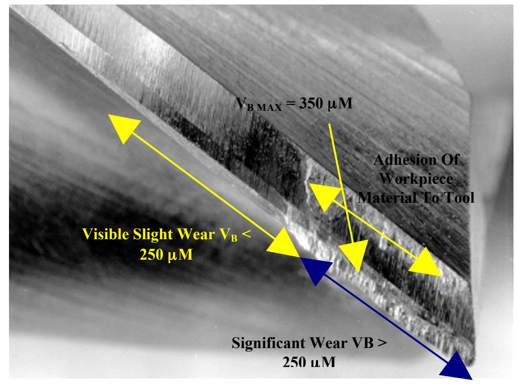
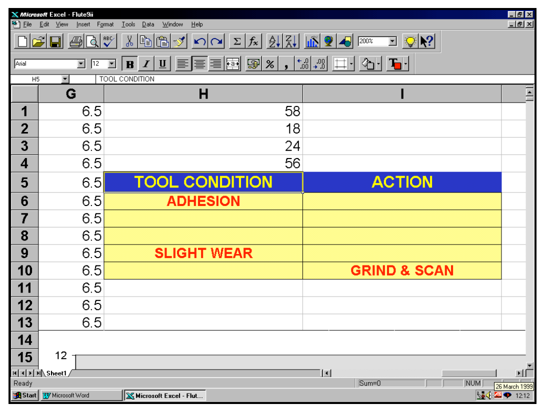


Fig. 6 : Visual verification of cutting tool condition.



	G	H	I
1	6.5	58	
2	6.5	18	
3	6.5	24	
4	6.5	56	
5	6.5	TOOL CONDITION	ACTION
6	6.5	ADHESION	
7	6.5		
8	6.5		
9	6.5	SLIGHT WEAR	
10	6.5		GRIND & SCAN
11	6.5		
12	6.5		
13	6.5		
14			
15	12		

Fig. 7 : Condition / action table for worn tool.

CONCLUSION

The work described here confirms the application of laser scanning as a viable method for automatically monitoring the condition of cutting tools. Future work hopes to demonstrate 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 development will remove the requirement for the separate inspection station, used in the presented implementations of the system. 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. Alternatively, in unattended machining systems, the scanner can be configured to communicate directly with the machine control unit. In this way, selection of defective tools can be inhibited and consequential damage to work-pieces avoided.

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