J39

On-machine measurement of workpieces with the cutting tool

Liu Zhan-Qiang
Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Hong Kong
Patri K. Venuvinod
Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Hong Kong
V.A. Ostafiev
Department of Manufacturing Engineering, National Technical University of Ukraine, Kiev, Ukraine

A new system for on-machine measurement of workpieces is described. The system is based on a fine touch sensor that enables the cutting tool itself to act as a contact probe to inspect the workpiece. The proposed measurement technology combines the Q-setter with the fine touch sensor. This low cost measurement system is applied to automatic workpiece setup and improving workpiece dimensional accuracy on a CNC turning center. It is shown that using the proposed measurement system results in workpiece setting time decrease and workpiece machining accuracy improvement. The development of the on-machine measurement system makes the fine touch sensor extremely attractive for CNC machine retrofitting.

Integrated Manufacturing Systems
9/3 [1998] 168–172

[ISSN 0957-6061]

Introduction

Once a workpiece has been machined, its dimensions need to be inspected for quality control. The techniques for measurement of machined workpiece dimensions may be classified into three modes:

1 *In-process measurement.* The measurement takes place during the actual machining process without any interruption to the process itself. The information produced by measurement is provided continuously. Shiraishi carried out a survey of the in-process technique for workpiece dimension, profile, and surface roughness measurement (Shirashi, 1989). In-process measurement offers practical solutions for real-time measurement and quality control (Kohno, 1989). It is well known in grinding applications of cylindrical parts. It is difficult to use in turning operations where there may be massive amounts of high speed swarf and coolants disturbance (Gibson and Hoang, 1994; Smith, 1989). However, further work is being undertaken in research facilities into these and other problems (Grosvenor *et al.*, 1991).

2 *In-cycle measurement.* Most machining and turning centers use the in-cycle measuring technique, which is also referred to as on-machine measurement. Unlike in-process measurement, the process must be stopped while the measurement takes place during the process cycle. With this measurement method, the workpiece can be assessed either between cuts or after completion, prior to removal from the set-up. It converts the machine tool into a coordinate measuring machine and adds a machining step to correct the workpiece while on machine (Gibson and Hoang, 1994; Mou and Liu, 1992).

3 *Post-process measurement.* The machined workpiece is removed from the process and transported by a suitable device to an independent inspection machine such as a CMM where the workpiece is inspected (Gibson and Hoang, 1994; Vorburger *et al.*, 1994). The major advantage of this method is that post-process measurement includes the effects of all error sources that affect the workpiece in a single setup. This is usually time-consuming and results in the risk of producing a large number of defective workpieces before the inspection results are known.

An ideal situation would be to employ in-process measurement. However, owing to the above disadvantages, on-machine measurement is preferable for a turning operation. On-machine measurement is a sensor-based machine tool measuring system. Today, wide ranges of various touch trigger probes have been applied to accurate on-machine measurement and inspection on CNC machining centers (Hermann, 1985; Janeczko, 1986; Lynch, 1994; Mou and Liu, 1992; Nickols and Martin, 1992; Szafarczyk and Missiewski, 1983; Zhou *et al.*, 1996). It is necessary that probe-compatible software and hardware are available for the machine tool to respond to touch probe signals. The controller uses the built-in commands or function codes to integrate the probing system (Zhou *et al.*, 1996). However, many old machines are normally fitted with non probe-compatible controllers. In this case, the probe cannot simply be applied to the machine tool since the machine controller does not react to the probe signals. There are an increasing number of techniques that can be used to retrofit the early CNC machine tools to enable on-machine measurement with a probe system. They are software solutions, hardware solutions and remote microcomputer control solutions (Coleman, 1990; Gadsby *et al.*, 1989; Gibson and Hoang, 1994; Zhou, 1996). The CNC retrofit can be obtained at a low cost.

This paper describes a new methodology for using a fine touch sensor to effect on-machine inspection for non probe-compatible

Liu Zhan-Qiang,
Patri K. Venuvinod and
V.A. Ostafiev
On-machine measurement of workpieces with the cutting tool

Integrated Manufacturing Systems
9/3 [1998] 168–172

Q-setters. This method is used to automate workpiece setup and turned workpiece diameter measurements.

Q-setter

A fairly recent development has been the mounting of a sensor on CNC machine tools. During the cutting tool setup, the sensor is moved to its working position, the operator jogs the tool tip into contact with it (Figure 1). When the tool tip is in contact with the sensor, a "beep" will be heard and the tool will stop while the tool offset is entered automatically (Figure 2). Before making the tool tip contact with the sensor again, the tool offset value remains constant. After finishing tool setup, the sensor is closed. This function is called the "Quick Tool Setter" and is abbreviated to "Q-setter". Q-setter facilitates tool setup when replacing a tool.

Fine Touch sensor measuring principle

The third author of this paper has patented a novel fine touch sensor. It does not require an analogue mechanism but relies on a switching principle. The fine touch sensor utilizes the fact that a MFWT (machine-fixture-workpiece-tool) system is an electromagnetic field generated by various electromagnetic sources such as servomotors as well as transformers. When the cutting tool is advanced to contact the workpiece, the electrically conductive MFWT system loop is closed and an electromagnetic current is generated around the loop. An electric coil that surrounds the cutting tool can be used to sense the loop current (Figure 3). The coil, which acts as an electrical transformer, has the necessary number of turns and cross-sectional area to output an amplified current.

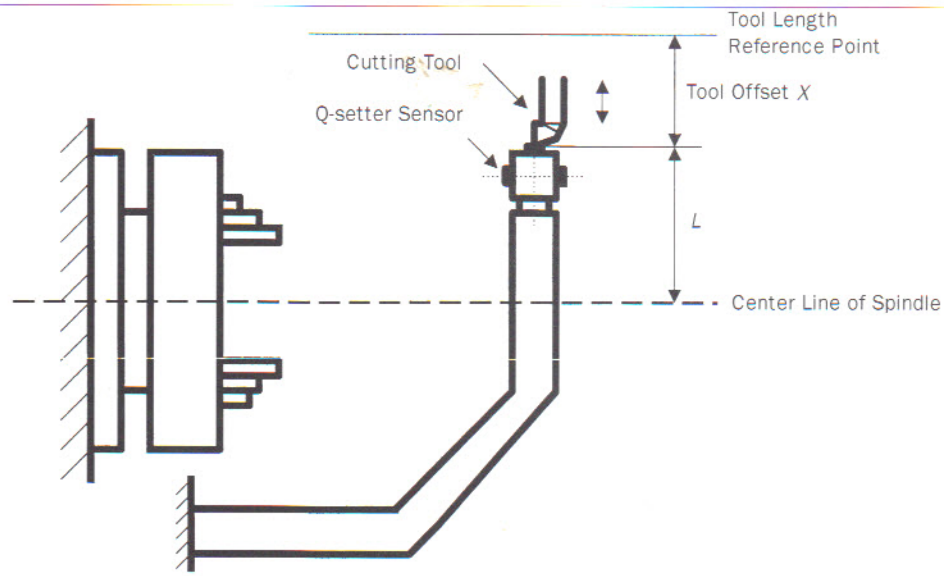
A separate circuit produces a switching "ON" signal when the current exceeds its presetting threshold. Thus, when the tool touches the workpiece during an inspecting cycle, the switching "ON" signal appears. This makes the cutting tool itself as a contact probe. The precision of the fine touch sensor was calibrated using a laser interferometer measuring system. It was shown that the contact detection accuracy of the fine touch sensor is much better than 1mm. Therefore, it is capable of measuring geometric dimensions of workpiece accuracy within 1mm.

However, the automatic determination of the movement for the cutting tool is difficult since the machine tool with non probe-compatible controller does not react to the sensor switching "ON" or "OFF" signals and there is no facility for any automated re-adjustment of the motion commands of the cutting tool. Thus, the fine touch probe cannot simply be applied to workpiece inspection.

Methodology

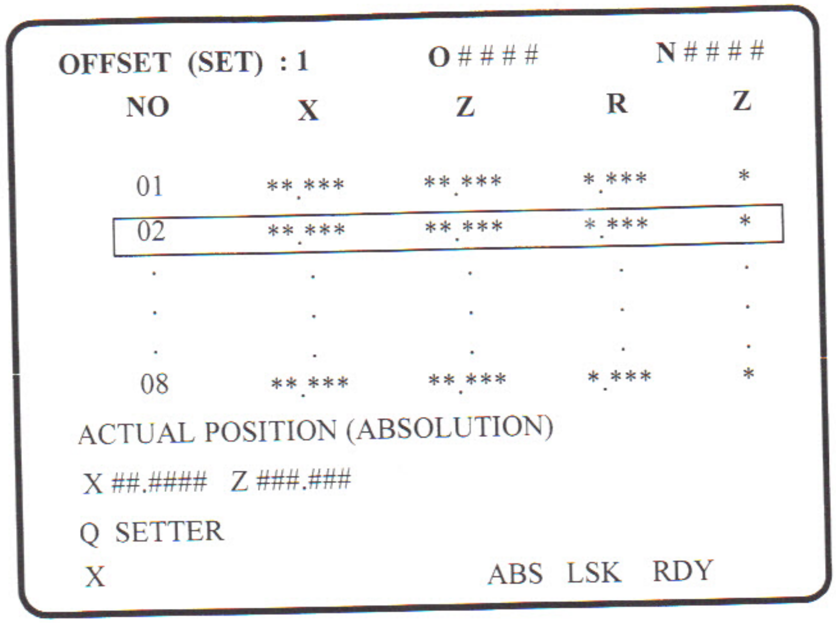
Considering the measuring function of the Q-setter and the probing strategy of the fine touch sensor, a novel methodology for applying the fine touch sensor to workpiece measurement on a CNC turning center is proposed. The CNC turning center has a Hitachi Seiki controller system and is equipped with a Q-setter. The output of the separate circuit that produces a switching "ON" signal of the fine touch sensor takes one place of the Q-setter output ports. It is possible to combine

Figure 1
Tool setup with Q-setter



Liu Zhan-Qiang,
Patri K. Venuvinod and
V.A. Ostafiev
On-machine measurement of workpieces with the cutting tool
Integrated Manufacturing Systems
9/3 [1998] 168–172

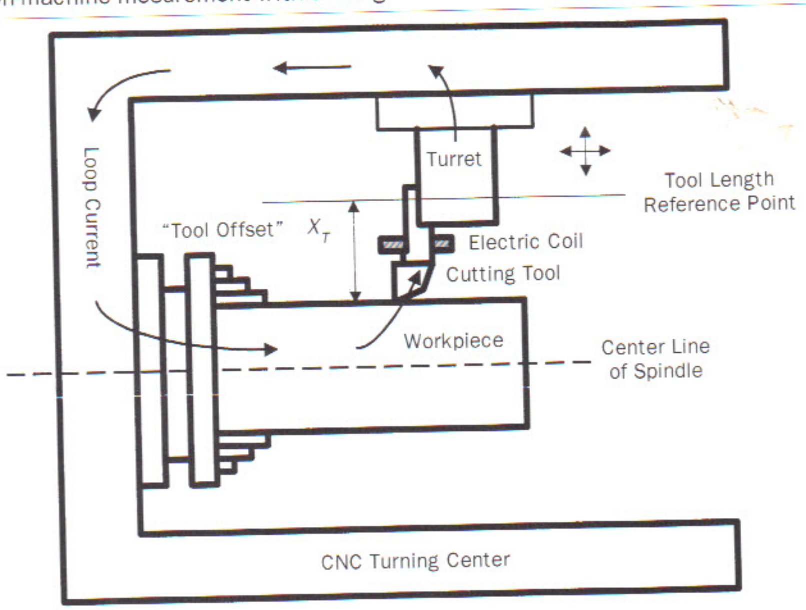
Figure 2
Tool offset displayed on screen



the Q-setter with the fine touch sensor to implement on-machine measurement of the workpiece.

Before applying the on-machine workpiece inspection, the tool tip is allowed to touch the center of the Q-setter. Then the offset X of the current using tool that is surrounded by the electric coil is automatically measured. A PC is integrated with the CNC turning center via an RS232 communication port. The measured tool offset is sent to the PC for data analysis.

Figure 3
On-machine mesurement with cutting tool



During the on-machine measurement cycle, the Q-setter is allowed to open a little so as to be in its setting position but not to interfere with the movement of the turret and the workpiece that is clamped by the chuck. On bringing the tool tip up to the workpiece, when the tool contacts the workpiece, a "beep" is heard while the switching "ON" signal appears and the tool tip stops automatically. A new "tool offset" X_T is inspected by the fine touch sensor automatically. The difference between the new "tool offset" and the offset during tool setup comes from the measurement base changing; one is the Q-setter and another is the workpiece. Then the actual workpiece diameter D at the contact point is given by:

$$D = 2 \times L + |X| - |X_T| \tag{1}$$

where, X is the tool offset when the cutting tool is in contact with the Q-setter. X_T is the "tool offset" when the cutting tool is contact the workpiece. L is the distance from the center of the Q-setter to the center of the spindle in X-axis direction and is provided by the machine tool manufacturer.

Both X and X_T are measured in the workpiece diameter direction. Before the cutting tool returns to its normal machining mode from the measuring mode, the tool offset is reset to its initial value X and Q-setter is closed.

The novel on-machine inspection approach has the following advantages:

- It extends the function of a conventional machine tool as a workpiece measuring

Liu Zhan-Qiang,
Patri K. Venuvinod and
V.A. Ostafiev
On-machine measurement of workpieces with the cutting tool

Integrated Manufacturing Systems
9/3 [1998] 168–172

machine and reduces other measuring equipment requirements. It makes the fine touch sensor extremely attractive for old CNC machine retrofitting.

- It combines the functions of the Q-setter sensor with the fine touch sensor so that it can be applied to a machine tool with a non probe-compatible controller.
- It is very economical to use the fine touch sensor compared with using expensive touch trigger probe.
- It eliminates the need for changing the tool for a probe before workpiece measurement since it uses the cutting tool itself as a contact probe. The cutting tool has two modes of operation: the machining mode and the measuring mode.

Setup of the workpiece

Workpiece setup has a significant influence on the machining accuracy. Errors due to workpiece incorrect setup may reach ±3 μm for machining centers (Andersson and Torvinen, 1991). In our research, the workpiece can be set to the approximate location which an operator or the handling device can easily reach. Naturally, there will be some deviations from the position where the part program is expecting the workpiece to be located. By bringing the cutting tool to touch the workpiece during the measurement cycle, some points are measured. The workpiece is reset according to the measured results. The workpiece finally finds its exact location by repeating this process of measuring, setting up and measuring. This decreases the setup time for the workpiece and thus increases the machine tool utilities.

Improved dimensional accuracy

Another benefit of the on-machine measurement system is to improve machined workpiece dimensional accuracy. For high precision workpiece machining, a series of machining passes is performed and the workpiece is measured between the passes. The workpiece dimensional errors are found and the next pass the machining program is adjusted so that the machining accuracy will be improved.

A turning experiment was performed using the fine touch sensor to make a high precision turned workpiece. After rough turning, a semi-finishing pass was performed using the identical cutting conditions with the final finishing pass.

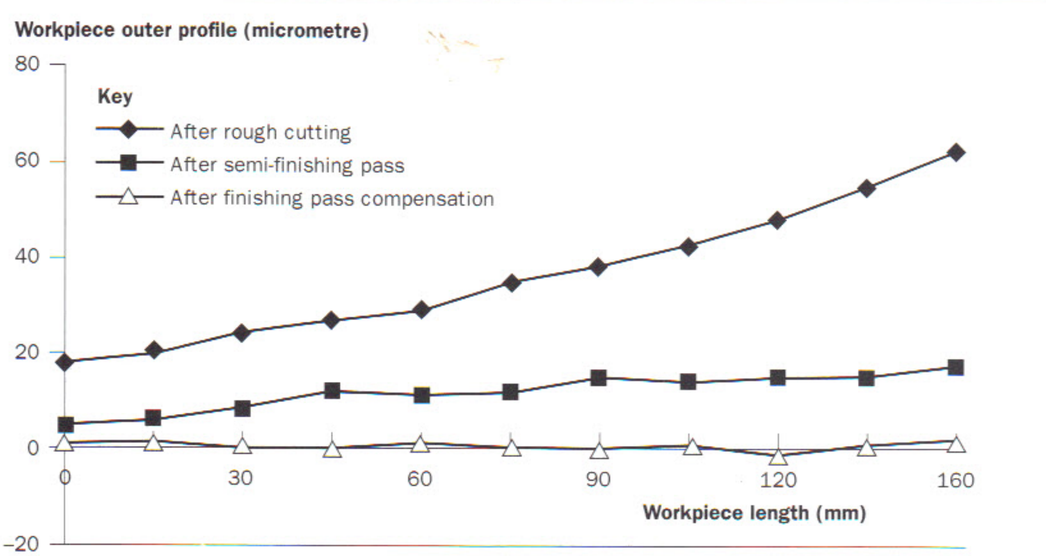
The actual diameters of the semi-finished workpiece were measured with the on-machine inspection methodology. The diameter errors for the semi-finished workpiece were determined and used to predict the expected errors for the final finished workpiece. A machining command was added to the workpiece final finishing pass program and had the following form:

G10L11P**X(U)*****Z(W)*****R*****Q*

where, G10L11 stands for the function for data setting; P is the number of cutting tool that acts as a contact probe; X(U) and Z(W) designate the tool offset absolute value (incremental value) along; the X and Z axis respectively; R gives the tool nose offset value; Q is the virtual tool nose direction.

The diameter error compensation was implemented in the final finishing pass by modifying the tool offset value X(U). The diagram in Figure 4 reveals the compensation

Figure 4
Machining error distribution along workpiece length



results reached. It is seen that the maximum error has decreased to 3 μm after compensation.

Conclusions

A new on-machine measurement technology was proposed which enables the cutting tool itself as a contact probe. The proposed measurement technology combined the Q-setter with a fine touch sensor to implement workpiece inspection. This method has an advantage in that the measuring devices are very cheap compared with the classical method of on-machine measurement. This low cost measurement system was applied to automatic workpiece setup. The application of the on-machine measurement also leads to the workpiece machining accuracy improvement.

References

Andersson, P.H. and Torvinen, S.J. (1991), "A concept for maintaining quality in flexible production", *Computers in Industry,* Vol. 17, pp. 247-55.

Coleman, J.R. (1990), "Take control with CNC", *Manufacturing Engineering,* Vol. 104 No. 5, pp. 35-40.

Gadsby, C., Balakrishnan, S. and Popplewell, N. (1989), "A microcomputer-based controller for milling machines", *International Journal of Advanced Manufacturing Technology,* Vol. 4 No. 2, pp. 168-81.

Gibson, P.R. and Hoang, K. (1994), "Automatic statistical processes control of a CNC turning centre using tool offsets and tool change", *International Journal of Advanced Manufacturing Technology*, Vol. 9 No. 2, pp. 147-55.

Grosvenor, R.I., Kharpoutly, C. and Martin, K.F. (1991), "In-process measurement problems in machine tool applications", *International Journal of Production Research,* Vol. 29 No. 2, pp. 357-74.

Hermann, G. (1985), "Process intermittent measurement of tools and workpieces", *Journal of Manufacturing Systems,* Vol. 4 No. 1, pp. 41-9.

Janeczko, J. (1986), "Touch probe calibration and measurement on CNC machining center", *SME Technical Paper,* IQ86-908.

Kohno, T. (1989), "In-process measurement and control for production process", *International Journal of Japan Society Precision Engineering,* Vol. 27 No.4, pp. 319-20.

Lynch, M. (1994), *Computer Numerical Control Accessory Devices,* McGraw-Hill Inc, New York, NY.

Mou, J. and Liu, R.C. (1992), "A method for enhancing the accuracy of CNC machine tools for on-machine inspection", *Journal of Manufacturing Systems,* Vol. 11 No. 4, pp. 229-37.

Nickols, F. and Martin, K.F. (1992), "Right diameter-first cut – lathe datuming probe", *Proceedings of the 29th MATADOR Conference,* pp. 291-301.

Shirashi, M. (1989), "Scope of in-process measurement, monitoring and control techniques in machining processes, Part 2: In-process techniques for workpieces", *Precision Engineering,* Vol. 11 No. 1, pp. 27-37.

Smith, G.T. (1989), *Advanced machining – the handbook of cutting technology*, IFS Publications, Kempston.

Szafarczyk, M. and Missiewski, M. (1983), "Automatic measurement and correction of workpiece diameter on NC centre lathe", *Annuals of the CIRP,* Vol. 32 No. 1, pp. 305-8.

Vorburger, T.V., Yee, K.W., Scace, B.R. and Rudder, F.F. Jr (1994), "Post-process control of machine tools", *Manufacturing Review,* Vol. 7 No. 3 pp. 252-66.

Zhou, E.P., Harrison, D.K. and Link, D. (1996), "Effecting in-cycle measurement with preteritic CNC machine tools", *Computers in Industry,* Vol. 28, pp. 95-102.

Liu Zhan-Qiang,
Patri K. Venuvinod and
V.A. Ostafiev
On-machine measurement of workpieces with the cutting tool

Integrated Manufacturing Systems
9/3 [1998] 168–172

machine and reduces other measuring equipment requirements. It makes the fine touch sensor extremely attractive for old CNC machine retrofitting.

- It combines the functions of the Q-setter sensor with the fine touch sensor so that it can be applied to a machine tool with a non probe-compatible controller.
- It is very economical to use the fine touch sensor compared with using expensive touch trigger probe.
- It eliminates the need for changing the tool for a probe before workpiece measurement since it uses the cutting tool itself as a contact probe. The cutting tool has two modes of operation: the machining mode and the measuring mode.

Setup of the workpiece

Workpiece setup has a significant influence on the machining accuracy. Errors due to workpiece incorrect setup may reach ±3 μm for machining centers (Andersson and Torvinen, 1991). In our research, the workpiece can be set to the approximate location which an operator or the handling device can easily reach. Naturally, there will be some deviations from the position where the part program is expecting the workpiece to be located. By bringing the cutting tool to touch the workpiece during the measurement cycle, some points are measured. The workpiece is reset according to the measured results. The workpiece finally finds its exact location by repeating this process of measuring, setting up and measuring. This decreases the setup time for the workpiece and thus increases the machine tool utilities.

Improved dimensional accuracy

Another benefit of the on-machine measurement system is to improve machined workpiece dimensional accuracy. For high precision workpiece machining, a series of machining passes is performed and the workpiece is measured between the passes. The workpiece dimensional errors are found and the next pass the machining program is adjusted so that the machining accuracy will be improved.

A turning experiment was performed using the fine touch sensor to make a high precision turned workpiece. After rough turning, a semi-finishing pass was performed using the identical cutting conditions with the final finishing pass.

The actual diameters of the semi-finished workpiece were measured with the on-machine inspection methodology. The diameter errors for the semi-finished workpiece were determined and used to predict the expected errors for the final finished workpiece. A machining command was added to the workpiece final finishing pass program and had the following form:

G10L11P**X(U)*****Z(W)*****R*****Q*

where, G10L11 stands for the function for data setting; P is the number of cutting tool that acts as a contact probe; X(U) and Z(W) designate the tool offset absolute value (incremental value) along; the X and Z axis respectively; R gives the tool nose offset value; Q is the virtual tool nose direction.

The diameter error compensation was implemented in the final finishing pass by modifying the tool offset value X(U). The diagram in Figure 4 reveals the compensation

Figure 4
Machining error distribution along workpiece length