МЕЖДУНАРОДНА КОНФЕРЕНЦИЯ "ТЕХНИКА НА ЗАДВИЖВАНЕТО'03"
INTERNATIONAL CONFERENCE "POWER TRANSMISSIONS'03"

THE MEASUREMENT OF TEMPERATURE DURING MACHINING

Prof.Dr.Ulvi SEKER[1],
G. U., Technical Education Faculty[1],
Ankara-Türkiye,
E-mail:useker@gazi.edu.tr

Assist. Prof. Dr. İhsan KORKUT[2],
G. U., Technical Education Faculty[2],
Ankara-Türkiye,
E-mail:ikorkut@gazi.edu.tr

Yakup TURGUT[3]
Gazi University[3], T.E.F.
Ankara-Türkiye,
E-mail:yturgut@gazi.edu.tr

Mehmet BOY[4]
Gazi University[4], T.E.F.
Ankara-Türkiye,

Abstract

In the metal cutting, the heat generated on the cutting tool is important for the performance of the tool and quality of the workpiece. The maximum heat is generated in the tool-chip interface during machining. The performance improvement in the machining has been provided by the knowladge of the cutting temperature on the tool. In this study, the temperature generated on the cutting tool and experimental methods for the measurement of temperatures were reviewed. Special attention was paid to embedded thermocouple method and an experimental setup was prepared to measure temperature on the cutting tool. To enable automatic data acquisition, this setup was connected to a computer with the necessary hardware and software. Advantech PCLD 8710 wiring terminal board and a PCI 1710 HG data acquisition and control card were used. An insulated K type termocouple (Ni-NiCr) was inserted into the hole on the cutting tool. **This study had been supported by Research Fund of Gazi University.**

KEY WORDS: TEMPERATURE, MACHINING, MEASUREMENT, CUTTING TOOL

1. Introduction

When machining metals and alloys most of these energy required to form the chips is converted into heat. Therefore, the temperatures genarated in the cutting zone is an important factor to take into consideration. This factor is of a major importance to the performance of the cutting tool and quality of the workpiece [1]. Temperatures in cutting zone depend on contact length between tool and chip, cutting forces and friction between tool and workpiece material. A considerable amount of heat generated during machining is transferred into the cutting tool and workpiece. The remaining heat is removed with the chips. The highest temperature is genarated in the flow zone. Therefore, contact length between the tool and the chip affecs cutting conditions and performance of the tool and tool life [2-3].

For the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. Several experimental and analytical techniques have been developed for the measurement of temperatures generated in cutting processes. Due to the nature of metal cutting, it is not possible to measure temperature precisely in the cutting zone and thus it is difficult to verify the theoretical results in a precise manner. Because of nature of the metal cutting, determination of internal temperatures on the cutting tool are very diffucult. For measuring of this temperatures generated in the cutting zone, several methods have been developed. Calorimetric method, thermocouple method, infrared photographic technique, thermal paints and PVD technique are some of them [4].

Thermocouples have always become a popular tool to be used in temperature measurements during metal cutting. This metod is very useful to indicate the effects of the cutting speed, feed rate and cutting parametres on the temperature. Thermocouples are conductive, rugged and inexpensive and can operate over a wide temperature range. In machining applications, a thermo electric emf is generated between the tool and the workpiece. With these method, the entire tool is used as a part of the thermocouple and the workpiece as the other part. The cutting zone forms the hot junction while a cold part of the tool and the workpiece forms the cold junction. These technique is easy to apply but only measures the mean temperature over the entire contact area and high local temperatures which may occur for a short period of time cannot be observed. It is necessary to have an accurate calibration of the tool and workpiece material as a thermocouple pair. Each tool-work combination requires a separate calibration and the results can be incorrect if a build up edge is formed [3].

Based on his measurements using the thermocouple method, Stephanson stated that the average emf is in tool workpiece interface. In general, this emf does not correspond to the average interfacial temperature. This is the case only if THA temperature is uniform or if the thermo-electric emf of the tool-work material combination varies linearly with temperature [5].

K.J. Trigger investigated the tool-work interface temperatures using the thermocouple technique. This work differs from the earlier work in that cemented carbid tools were used in machining steels instead of the HSS tools. Both the elements of tool-work thermocouple comprised of iron base alloys of similar basic lattice structure, a factor which can influence the tendency of the chip to form a built up edge on the tool and consequently cause erratic results. Also, he eliminated this factor and using different metals had been provided higher thermo-electric current thus increasing the accuracy of measurement [6-7].

D.L.Rall and W.H.Giedt used an instrumented tool holder to determine the average temperature at the chip-tool interface.

They used two HSS tools (with 0° and 15° back rake angles) instrumented with thermocouples located in the tool at the selected distances from the cutting edges. Extrapolation of the temperature measurements to the center of the tool-chip contact area gave values of the average tool-chip interface temperatures that are reported to agree reasonably well with the results of the other investigators.

K.J.Kuster employed (what) to determine the entire temperature field (a total of more than 400 points). Thermocouple holes of 0.32 mm were drilled by EDM in cemented carbide tools and a chrome-nickel thermocouple of 0.07 mm was inserted inside a nickel tube of 0.2 mm outer diameter and 0.14 mm inner diameter with proper electrical insulation in the drilled holes.

A.H Quereshi and F.Koenigsberger used a similar method by inserting the thermocouple in the tool but instead of using a large number of tools with the thermocouples at different locations, as in the case of Kusters. They ground the rake and clearance faces of the tool progressively to obtain the temperature distribution in the tool with only one initial hole in the tool for the thermocouple. They found the maximum cutting temperature was not at the cutting edge but at some distance away from it, the point of maximum temperature moving towards the end of the tool-chip interface contact with increase in speed and/or feed [9].

A method was developed to measure the temperature in the flank face of the tool wire of a material different from that of the workpiece and tool. This wire is inserted into the workpiece into a hole of a small diameter and is insulated. When the material is been cut, this wire will also be machined, and when this happens a thermocouple is formed between the wire and the tool. With regard to the results obtained, the temperature of the tool flank face is affected little by the cutting speed,fed rate and depth of cut. The temperatures obtained by this method are lower than when using the tool-work thermocouple method [10].

The temperature distribution in the tool may be obtained by using information about the changes in the hardness and microstructure of the steel tool. It is necessary to calibrate the hardness of the tool against the temperature and time of heating, and samples of structural changes at corresponding temperatures. These methods permit measurement of temperatures to an accuracy of ±25°C within the heat-affected region. However, these methods are arduous and difficult to use [11].

K.Okushima and R. Shimodo measured the temperature distribition within tool. They designed a special split-tool and were able to measure the temperature in the vicinity of the cutting edge because the paint, sandwiched between two halves of the split-tool, was protected from being scraped off by chips [12].

A new method to measure the temperature distribition in cutting tools had been investigated by T.Kato and H.Fuji. In this method, a thin PVD film deposited on a cuttig tool is used as a thermal sensor. Various films of different materials are deposited to determine the location of multiplicity of isoterms at different temperatures [13].

W.Grzesik investigated the influence of tool-work interface temperature when machining an AISI 1045 and an AISI 304 with coated tools. A standart K type of thermocouple inserted in the workpiece was used to measure the interface temperature. The friction on the flank face had a big influence on the heat generated at about 200 m/min cutting speed [14].

O'Sullivan and Cotterell mesured the machined surface temperatures two thermocouples inserted into the workpiece when machining aluminium 6082-T6. The results indicated that an increase in cutting cutting speed resulted in a decrease in cutting forces and machined surface temperatures. This reduction in temperature was attributed to the higher metal removal rate which carried more heat being carried away by the chip [15].

In this study, the methods of temperature measurement during machining were reviewed and a temperature measurement set-up based on embedded thermocouple method was prepared. To enable automatic data acquisition, this setup was connected to a computer with the necessary hardware and software.

2. Heat generation during the machining

During metal cutting, the metal is deformed plastically in shear zone and is removed from this region in the form of chips. The workpiece material ahead of the cutting edge is deformed plastically and removed in from the workpiece materials in the form of chips. The energy required to deform the workpiece material and the chips is mainly converted into heat. As shown in Figure 1, there are three zones in which the heat is generated:

- Primary deformation zone, where plastik deformation takes place and Q_S is geneareted,
- Secondry deformation zone, where the deformation takes place in the tool-chip interface and as the result of friction force Q_C occurs,
- Tertiary deformation zone, where the heat is generated due to friction beween tool clearance face and newly generated workpiece surface, Q_F.

Thus, the total heat, Q_T can be obtain by the following equation:

$$Q_T=Q_S+Q_C+Q_F$$

When a material is deformed elastically, the energy required for the operation is stored in the material as strain energy, and no heat is generated. In metal cutting the material is subjected to extremely high strains and the elastic deformation forms a very small proportion of the total deformation whereas plastic deformation forms large proportion of the total deformation. Therefore; it may be assumed that all the energy is convert into heat. Heat generated tool-work interface is of importance to the tool performance [16].

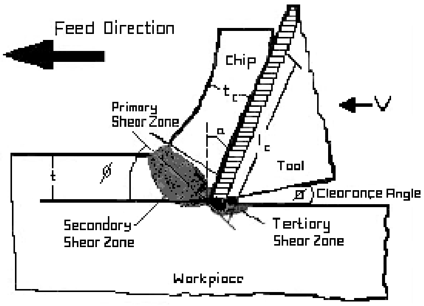

Figure 1. Generation of Heat in Ortogonal Cutting

The rate of the metal removal can be limited when the machining high melting point metals and alloys. The heat generation in the tool-work interface was treated on the basis of classical friction theory by many investigators. As the result of cutting forces, friction occurs between tool and workpiece in machining. In a simple manner, the total work carried out can be divided into three quantitites: (i) work to shear the material to form the chip and the new surface, (ii) work to move the chip over the rake face of the tool and (iii) the work necessary to move the freshly cut surface over the flank face of the tool [17].

The work to shear the material to form the chip involves the dissipation of heat resulting from internal friction, therefore; this is necessary to reduce the friction between the tool and chip or workpiece, which may involve internal friction because of seizure between the surfaces. Increasing the metal removal rate means that more material can be cut in a shorter time and this has been achieved by increasing the cutting speed, the feed rate and the depth of cut. To do this in an economical way depends on many factors related with metal cutting, namely the machine tool, the cutting tool, the cutting fluid and the materials. The increase in power to remove more material in a shorter time increases the heat generation near the cutting edge of the tool and the power consumed in metal cutting is largely converted into heat. This heat is dissipated by the four elements in metal cutting systems: the cutting tool, the workpiece, the chip formed and the cutting fluid [2-3].
The cutting fluids used with some cutting operations play a very important role and many operations cannot be carried out efficiently without cutting fluid. Among their functions, cutting fluids are used to cool the tool, workpiece and machine tool. The coolant can act as a lubricant, too [18].

In an early work, M.E.Merchant, M.Field and V. Pisponem related the heat generation during metal cutting to the frictional forces. In their study, they took into consideration the chip geometry, the power consumption and the cutting parameters [17-19].

According to E.M.Trent the heat generated at the tool-work interface is of major importance in relation to the tool performance, and is particularly significant in limiting the rates of metal removal. Along the greater part of the contact between the chip and the tool, there is a seizure zone where these two materials are in close contact. There is no relative movement between the chip and the tool at the surface of the tool. [18].

3. Experimental set-up

The set-up was prepared to be mounted on a precision lathe. The tool holder used was Stellram SSBRC 2525M12 and the carbide inserts used were Stellram SCMW12M508E (P10-P20). The workpiece used was an AISI 1040. A Standart K-type termocouple was inserted the tool. PLCD 780 wiring terminal board, PCI 1710 HG data acquisition and control card and a computer were used. Tool and workpiece were insulated from the machine tool. The insulated termocouple was inserted in sensitive hole in the tool drilled using EDM. After thermoelectric circuit was made, one of the copper wires was connectted the cold junction were maintained in an ice-bath. After these, copper wires were connected to PCI 1710 HG data acquisition and control card. The thermoelectric circuit was connected as shown in Figure 2. In Figure 2, thermocouple were inserted and the tool formed the hot junction whereas another wire which was inserted in an ice-bath formed the cold junction. PC 710 HG card was used to measure the emf genareted at this junction.

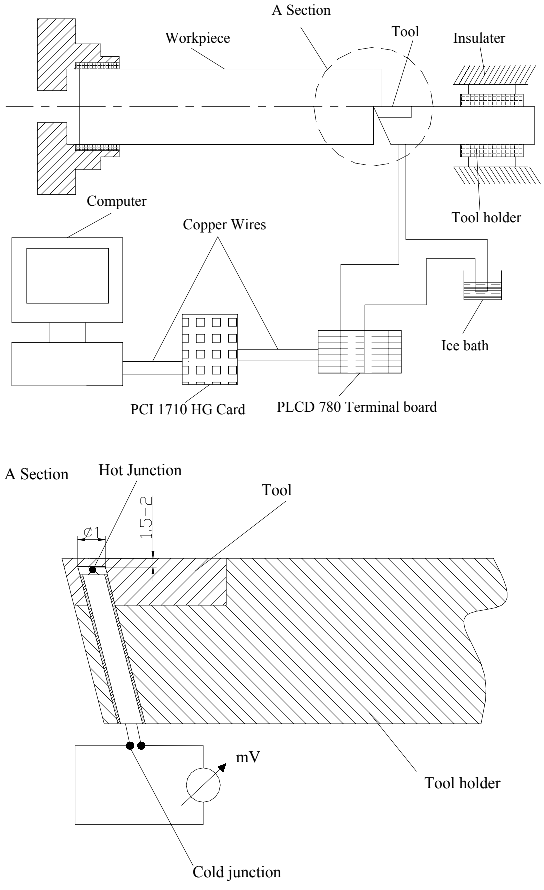

Figure 2 : The experimental set up of the embedded thermocouple method

4. Calibration of embedded tool-workpiece thermocouple

A long chip from AISI 1040 was welded to the tool by resistance welding method. The chip was placed in an area near the hole which was drilled before. It was considered that the concentration of heat is high at this point. The chip and tool holder was connected to the terminal board with a conductive wire. Also, the ends of the thermocouple wires were connected to the terminal board and a conductive curcuit, as shown Figure 3, was formed. After this, the emf of the tool-workpiece thermocouple and embedded thermocouple was calibrated using an oxygen-gas flame at the room temperature.

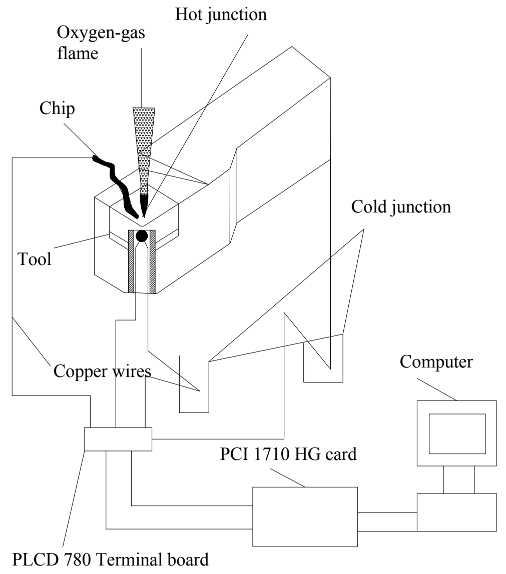

Figure 3. Calibration of embedded themocouple and tool-work thermocouple

5. Result And Discussion

Standard thermocouples embedded in the cutting tool or workpiece material can be used to measure the temperature at a single point or at different locations to determine the temperature distribution in the tool. They can also be positioned at the interface between an indexible insert and the tool holder. Embedded thermocouples have been found to provide a good indication of the transient changes in frictional heat generation that accompany contact area changes. This tecniquie has some limitatitions: (1) the placement of the thermocouple can interfere with the heat flow, (2) it is a tedious procedure to estimate with accuracy the gradient of temperature, (3) there are difficulties in driling holes. The distinguishing characteristics of tool temperature measurement are as follows: firstly, access to the measuring point is limited, secondly, the area to be measured is very small, and thirdly, an extremely steep gradient of temperature exists in the small area of the cutting edge. The tool and the workpiece must be isolated electically from the machine tool to obtain an accurate signal.

6. Literature

1. **Gökkaya,H.,Şeker,U.,and İzciler, M.** “ The Review of Experimental Methods to Measure the Generated Heat at the Tool-Workpiece İnterface, and the Evaluation of the Experimental Results Using Different Metods ”, MATIT, pp.91-105,2001, Konya-Türkiye.

2. **Bever, M.B.,Marshall,E.R. and Ticknor,L.B.**, “ The Energy Stored in Metal Chips During Ortogonal Cutting”, J.Appl. Phys., 24, pp.1176-1179, 1953.

3. **Shaw,M.C.,** “Metal Cutting Principles”, Oxfort University Press, London, 1984.

4. **Silva,M.B. and Wallbank,J.**, “Cutting Temperature: Prediction and Measurement Methods a Review”, Journal of Materials Processing Technology 88, pp.195-202,1999.

5. **Stephenson,D.A.**, “Tool-Work Thermocouple Temperature Measurement” Trans. ASME.J. Eng. Ind. 115, pp.432-437,1993.

6. **Trigger,K.J.**, “Progress Report No:1 on Chip-Tool Interface Temperature”, Trans. ASME., 70, pp.91-98,1948.

7. **Trigger,K.J.**, “Progress Report No:2 on Chip-Tool Interface Temperature”, Trans. ASME, 71, pp.163-174,1949.

8. **Rall, D.L. and Gied, W.H.**, “Heat Transfer to,and Temperature Distrubition in,a Metal Cutting Tool” Trans ASME 78, pp.1507-1515,1956.

9. **Komanduri,R. and Hou.Z.B.**, “ A Review of The Experimental Techniques for The Measurement of Heat and Temperatures Generated in Some Manufacturing Processes and Trİbology” , Tribology international, 34 (10), 653-682, October 2001.

10. **Smart,E.F. and Trent,E.M.**, “Temperature Distributions in Tools Used for Cutting Iron,Titanium and Nickel”,Int.J. Prod.Res.13 pp.265-290,1975.

11. **Hirao, M.**, “Determining Temperature Distribution on Flank Face of a Cutting Tool” J. Mater. Sharp. Technol. 6, pp.143-148,1989.

12. **Okushima, K. and Shimodo, R.** “ The Cutting Temperature” ,BJSME, Vol.23 pp. 73-77, 1957.

13. **Kato, T. and Fuji, H.**, “ PVD Film Method for Measuring the Temperature Distribution in Cutting Tools”, Journal of Engineering for Industry, Vol.118, pp. 117-122, Feb. 1996.

14. **Grzesik, W.**, “ Experimental İnvestigation of the Cutting Temperature When Turning with Coated Indexable Inserts”, International Journal of Machine Tools and Manufacture 39, pp.355-369, 1999.

15. **O’Sullivan, D. ve Cotterell,M.**, “Temperature Measurement in Single Point Turning” Journal of Metarial Processing Technology, Vol.118 pp. 301-308, 2001.

16. **Bootthrody, G.**, “Fundementals of Metal Machining and Machine Tools”, McGraw-Hill,New York,1981.

17. **Pispanem,V.**, “ Theory of Formation of Metal Chips” J. Appl. Phys.19, pp.876-881,1984.

18. **Trent.E.M.**, “Metal Cutting,2nd ed., Butterworths”, London,1984.

19. **Merchant,M.E. and Field, M.**, “ Mechanics of Formation of the Discontinuous Chip in Metal Cutting”, Trans ASME 71, pp.4-21,1949.