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On-line Tool Breakage Detection Using Acoustic Emission, Cutting Force and Temperature Signals in Turning

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Abstract: *In this study, the experimental study which is performed the variation of some signals based on detection of tool breakage and its results exists. For this purpose a sensor fusion was composed using acoustic emission (AE), tangential cutting force (F_C) and temperature signals. In the experimental design, there are 3 factor which are tool tip, cutting speed and feed and each of them have 3 level. 27 experiments were performed based on full factorial design principle. AISI 1050 as workpiece material and cutting tools which have TCMT 16T304 tool geometry and 3 different quality was used. According to obtained results, it was seen that the output of sensor fusion values which consists of AE, F_C, and temperature signals are compatible with each other and measured values at on-line detection of tool breakage.*
Keywords: *Acoustic emission, cutting force, temperature, tool breakage, turning*

I. Introduction

Manufacturing processes is a very difficult operations to control because of the existence of various number of parameters and variable and occurring changes one of them can affect the each other more or less. Changes in the cutting area occurs rapidly and because of the high temperature, pressure and friction, the possible malfunctions can cause great losses. One of the major losses is tool breakage which occurs by reason of progressive and uncontrolled tool wear. Tool breakage can cause the damage of workpiece and tool holder or on the other hand it can harm machine tool and operator. To avoid tool breakage, sensors are used to transfer information rapidly, reliably and sensitively. Choice of sensor is determined according to operation types and using more than one sensor a multi sensing systems can composed. The main purpose of multi sensing system is to acquire more reliable information by using sensors which complete the weak sides of each other. For this purpose, cutting force, AE, vibration, motor power, motor current, sound and temperature signals were used in many work for detection of tool breakage, progressive tool wear, workpiece accuracy, surface roughness and chip formation monitoring at different machine tools.

In the past, a lot of study were performed about on-line detection of tool breakage in turning using various sensor fusion systems: Lee et al. [1], Jemielniak and Otman [2], Yalçın and Sağlam [3] used AE and cutting force signals, Işık and Çakır [4,5] used cutting force signals, Neslusan et al. [6] used two AE sensors which have different frequency ranges for early sensing of tool breakage in turning.

Lee et al. [1], determined the breakage moment with the sudden increase of AE signal and sudden drop of cutting force signal subsequently during machining of the AISI 1045. Jemielniak and Otman [2], evaluated the success of the AE signal parameters which are RMS, skew and kurtosis in detecting tool breakage in turning. According to them, skew and kurtosis coefficients are more successful than the RMS value because of showing promising symptoms. Yalçın and Sağlam [3], monitored the tool breakage during machining AISI 1040 and AISI 4140 workpiece materials. They developed an early warning system using AE signal burst at the moment of breakage and the system estimated tool breakage moment successfully.

Işık and Çakır [4], found out that %25 increase at cutting force indicates tool breakage with a software system during machining AISI 1050 workpiece material. Işık and Çakır [5], used a software system which send a warning signal to pc monitor when tangential cutting force exceeds preset threshold level during machining AISI 1050 workpiece material. The composed system detected tool breakage with success of %84. Neslusan et al. [6], investigated both tool breakage and chip formation using the two AE sensors which have different frequency ranges. Low frequency ranged sensor (15-180 kHz) is used for crack initiation sensing and high frequency sensor (100-1000 kHz) is used for sensing of cracks and plastic deformation.

In this study, 27 experiments were performed using tool tip, cutting speed and feed as an input factor for detecting on-line tool breakage during turning the workpiece of AISI 1050. For this purpose dynamometer, AE and temperature sensors were used and sensor fusion was composed with tangential cutting force, AE and temperature signals. The behavior of sensor signals and the success of detection of tool breakage and cutting parameters at the moment of breakage were evaluated. The behaviors of each sensors signal were investigated both graphically and numerically.

II. Material and Method

2.1 Experiment Parameters:

The experiments were performed at conventional turning lathe (Tezsan T165-MF). The test samples of AISI 1050 workpiece materials which have ø50x400 dimensions were machined between headstock and tailstock. In the experiments cutting tools (Bohler TCMT 16T304) which have same geometry and 3 different quality were used. Each of cutting tool tip was used in one experiment. 27 experiments based on full factorial design principle were performed using cutting speed, feed rate and tool quality as experiment parameters. Cutting depth is kept constant 2 mm and experiments were performed at dry cutting conditions. Cutting parameters can be seen at Table 1.

Table 1 Cutting parameters for the experiments with 3 factor and 3 level

Parameters	Parameter Value		
Cutting Speed (m/min)	135	194	207
Feed Rate (mm/rev)	0,171	0,214	0,256
Tool Type	P10	P25	P35

2.2 Experimental Design:

Experimental installation include machine tool, sensors, measurement devices and a computer (Fig. 1). The measurement of tangential cutting force and the temperature at the tool tip were performed by sensor (TelC) which can get 10 measurement in a second. Dynamometer can measure cutting forces in 3 axis. Temperature sensor has 300-800 °C measurement range and measure the temperature at the tool tip with radiation. AE signals are measured with AE sensor (Kistler 8152B111/121) and sensor has 50-400 kHz measurement range. AE and temperature sensors are placed on dynamometer with screw connection (Fig. 2). AE sensor is fitted on the dynamometer while the temperature sensor is positioned 20 cm far from the tool tip. Several trial were carried out in order to find the best placement of AE sensor where the AE signal level is higher.

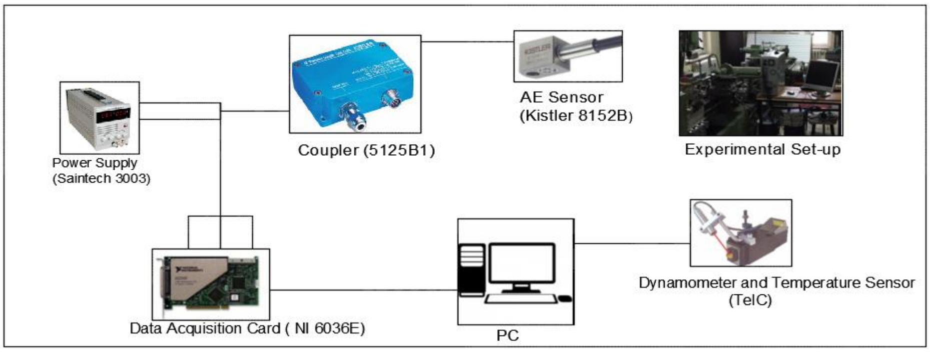

Fig. 1 Experimental design

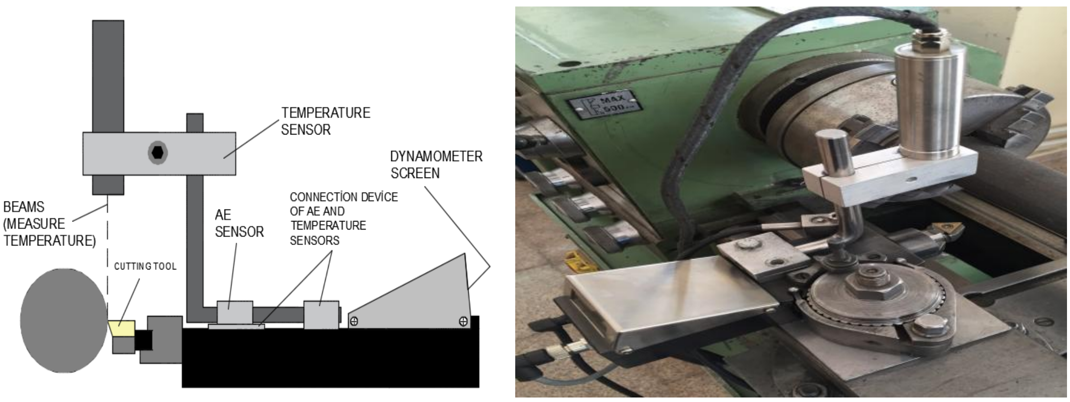

Fig. 2 Schematical demonstration of sensor fusion and sensor integration on machine tool

III. Experimental Results

The conducted experiments are indicated that medium-hard (P25) and tough (P35) tool tips have only flank wear and chipping, on the other hand chipping and breakage occurred at hard (P10) tool tips. It can be shown in the Fig. 3 and Fig. 4 that AE signal burst occurs many times because of chipping. But tangential cutting force signal has little fluctuations at this moments. It is understood from this signal patterns that only AE signal burst refers to chipping. On the other hand, signal burst of AE and cutting force signals at the same time refers to tool breakage.

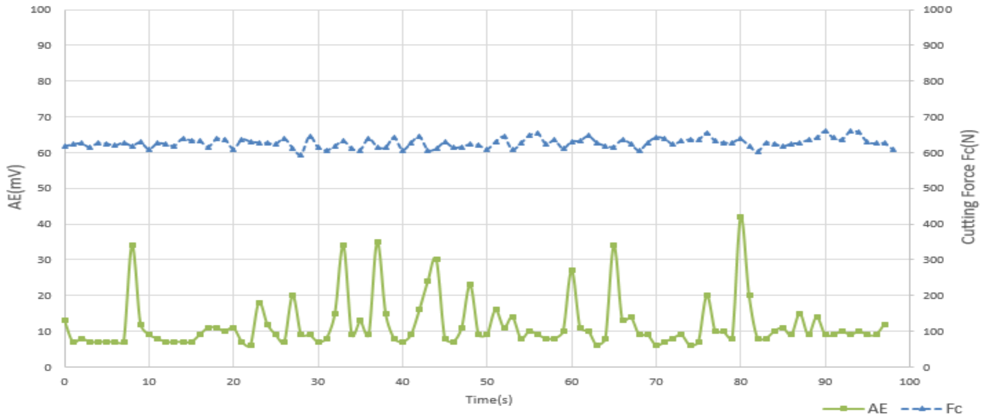

Fig. 3 AE and cutting force signals at this cutting conditions: T=P35, v=135 m/min, f=0,214

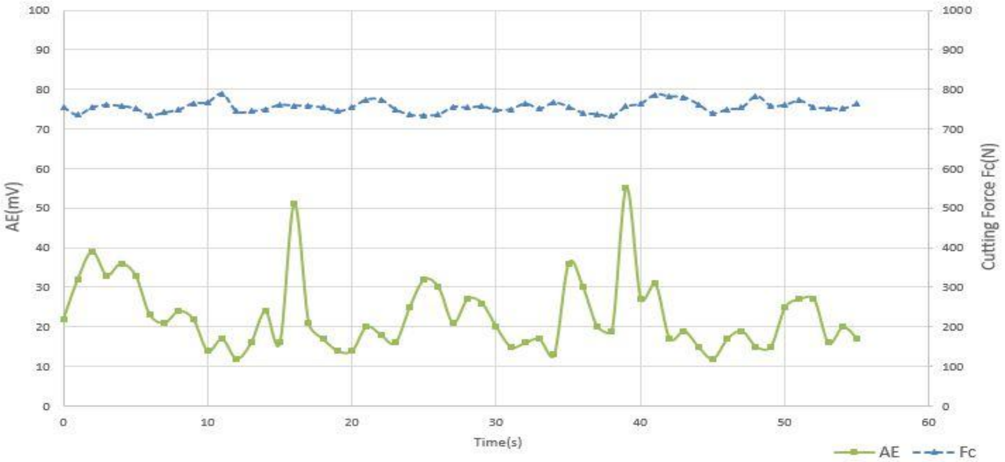

Fig. 4 AE and cutting force signals at this cutting conditions: T=P25, v=194 m/min, f=0,256

The signal graph which belongs to tool breakage occurred experiment is shown in Fig. 5. Experiment parameters are v=207 m/min, f=0,171 mm/rev, T=P10 at the experiment that breakage occurred. The picture of tool tip used in this experiment is shown in Fig. 6.

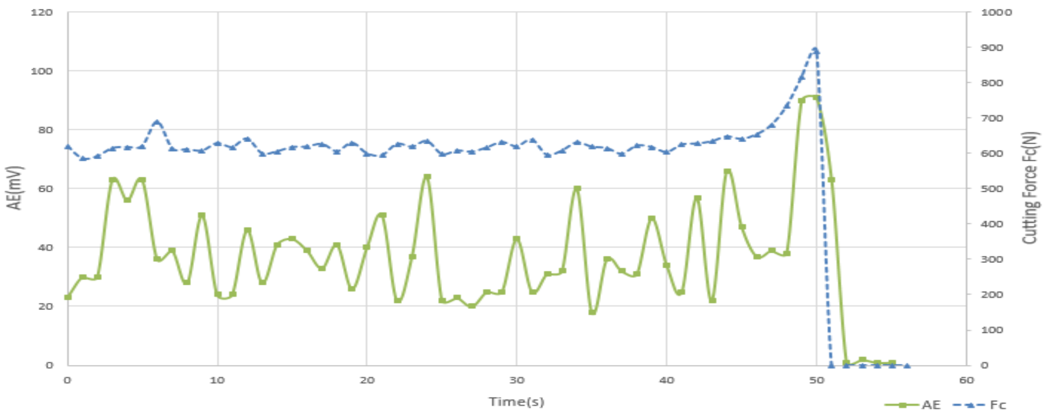

Fig. 5 AE and cutting force signals at the breakage moment

When AE signals are observed chipping is occurred during machining. Both AE and force signal burst at the moment of breakage and after the tool-workpiece contact is over, both of them suddenly decrease. From this, it was seen that chosen sensors are successful at detection of tool breakage. But one thing is certain that AE sensor is more sensitive than dynamometer in detection of tool breakage.

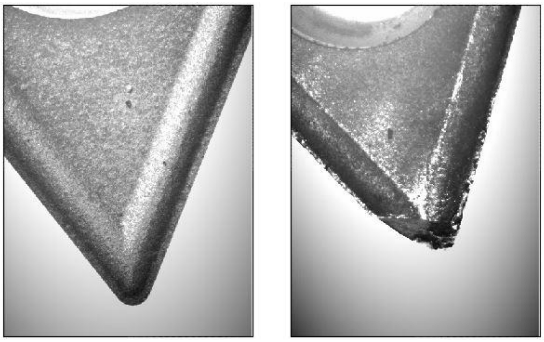

Fig. 6 The picture of tool tip before and after machining

IV. Conclusions

The committed work contains 27 experiment which performed for tool breakage detection during machining of AISI 1050 workpiece material. Success of AE sensor, dynamometer and temperature sensor are analyzed in this event. Every sensor signal changes depend on time and according to cutting conditions different signal patterns occurs. During progressing tool wear each of sensor signal is fluctuated and at the breaking moment they burst and right after that decrease suddenly. But each of them changes at different ratio. Considering this, sensor signal behaviors are investigated both graphically and numerically.

In the experiment which has the maximum cutting speed and minimum feed tool breakage occurred. During machining hard tools, chipping occurred mostly and the breakage observed at this tool type (P10). Committed sensor fusion detected the breakage moment successfully. At the breakage moment, tool-workpiece contact area increases firstly and this causes both tangential cutting force and AE signal burst. After the breakage, because of tool and workpiece contact is over, sudden drop is occurred each of sensor signal. This changes at the sensor signals is shown that this committed system which is done for the early estimation for tool breakage is successful.

When it is compared for each sensor signal, the ratio between the signal value at the breakage moment and the average value till the breakage moment, it is seen that AE signal increases 2.5 times, tangential cutting force signal increases %42 and the temperature signal increases %5 for each sensor signal. This result is shown that AE signal is very successful at tool breakage detection, on the other hand cutting force and temperature signals should be complementary and supply additional knowledge to make a decision about the event.

This paper was prepared from the master thesis named “The Prediction of Tool Fracture and Progressive Tool Wear in Turning Using Acoustic Emission and Cutting Force Signals”.

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